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TRACK TAPERING SYSTEM
Final Report

J. C. Hake, R. F. Johnson, and M. H. Marvin

November 1993

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ARNOLD ENGINEERING DEVELOPMENT CENTER

UNITED STATES AIR FORCE

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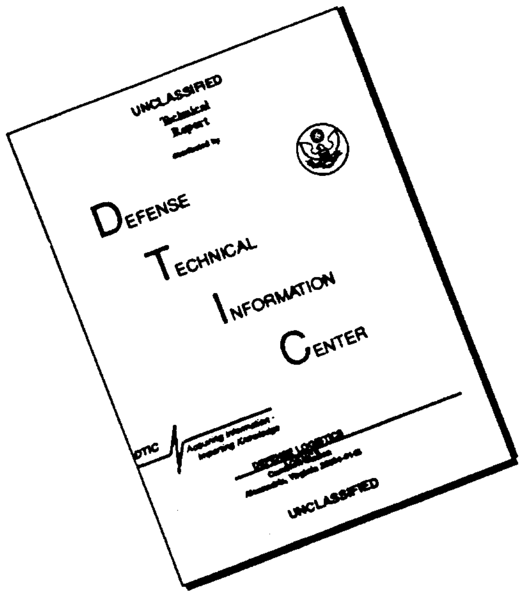

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The Hypervelocity Test Track at Arnold Engineering Development Center (AEDC) is 880 feet long and is used for testing high-speed projectiles. Under many circumstances, it is desirable to taper the final 200 feet to improve the reliability of the projectile tests. A Phase II SBIR has been completed to implement a rapid track tapering system at the Hypervelocity Test Track. During this project, three key subsystems were designed and built: mechanical hardware to allow rapid manual adjustment of the rail positions in the track, custom gages to measure the rail positions, and stand-alone software to plan all the rail positions for a desired track taper. The mechanical hardware included modifications to the existing track hardware to incorporate new mechanisms for adjustment of track taper. The rail position gauges allow direct measurements of the track diameter and centration without requiring disassembly of the track. The taper planning software provides a spreadsheet format for easily determining the required track diameter at each adjustment point along the track. The system was installed and tested at the Hypervelocity Test Track and AEDC personnel were trained in the use and maintenance of the equipment.

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INTRODUCTION

This document is the final report for Phase II of the Track Tapering System Project, Contract Number F40600-90-C-0024. This project is the second phase of an SBIR program to provide rapid track tapering for the Hypervelocity Test Track facilities at Arnold Engineering Development Center (AEDC). During Phase I, the concepts for a track tapering system were developed, tested, and verified. During this phase, these concepts have been developed, fabricated, and installed in the track.

The emphasis of this report is on the design and fabrication of the track tapering system. The remainder of this section describes the Hypervelocity Test Track and gives a statement of the problem for this project. This is followed by a discussion of the specific objectives for the program and an overview of the track tapering system. Next, the specific design, fabrication, and testing of each major subsystem is discussed in detail. Finally, the installation of the hardware and training of AEDC personnel is presented. A complete guide to operating the system can be found in QUEST Technical Communication No. 378, "User's Manual, Rail Position Gauge."

BACKGROUND

The Hypervelocity Test Track is located in G-Range at AEDC. This facility is used for testing projectiles at speeds up to 24,000 feet per second. A light-gas gun is used to propel the projectiles down the track. As shown in Figure 1, the track is composed a series of precision bored tubes with four orthogonal rails mounted inside. The rails provide a guiding surface for the projectiles as they fly down the track. The spacing between the rails is 3.3 inches. Each tube and rail assembly is ten feet long and is called a track section. The track sections are suspended from an outer pressure vessel. Flanges are used to connect the sections to form a continuous track 880 feet long. At the exit of the track is a recovery tube that is 520 feet in length. The recovery tube is used to decelerate the models for recovery and analysis.

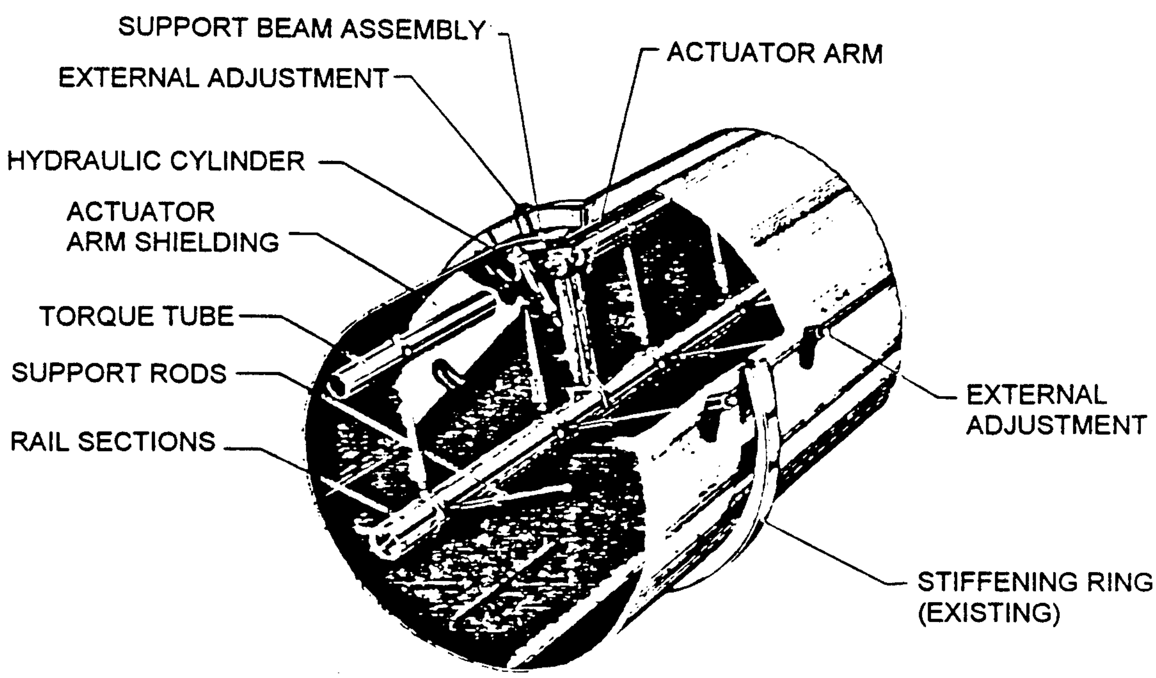


Figure 1. G-Range Test Hypervelocity Test Track

Under certain circumstances, is it is desirable to taper the final 200 feet of the Hypervelocity Test Track to compensate for the wear on the projectiles. By doing so, the projectiles are prevented from ricocheting from rail to rail as they progress down the track. In addition, the taper provides a smooth transition from the track to the recovery tube.

Previously, a significant effort was required to adjust the taper in the track. Each section had to removed from the track so that the individual rails could be shimmed to provide the correct distance between the rails as well as maintain the concentricity of the rails with respect to the support tube. When the section was returned to the track, it had to be aligned with respect to its neighbors. In particular, each rail had to be checked for proper alignment with the uprange and downrange track sections. Misalignments of the rails could have resulted in the catastrophic destruction of a projectile, causing damage to the G-Range facility. A system to allow rapid changes to the taper of the final 200 feet of the Hypervelocity Test Track has been developed and installed in this program.

The following documents are listed for reference and may provide the reader with a broader understanding of the background of this program:

- "Remote Track Tapering Final Report," August 1989, Flow Research Report No. 483.
- "Track Tapering System," Phase II Proposal, October 1989, Flow Research Proposal No. AIC220016.
- "Ballistic Range Track Tapering System Phase II Statement of Work," February 1990.

STATEMENT OF THE PROBLEM

To reduce the time and expense of adjusting the taper on the Hypervelocity Test Track, a system was needed to allow the track taper to be adjusted without removing any sections from the track. The tapering system had to calculate, adjust, and verify rail positions along the last 200 feet of track. The system had to be capable of providing a linear taper starting at a 3.3-inch diameter at the uprange end to a 3.3- to 3.1-inch diameter at the downrange end of the track. The system had to maintain the concentricity of the rail diameter with respect to the support tube, and it needed to provide adequate stiffness to prevent rail movement during use.

PROGRAM OBJECTIVES

The specific objectives for this Phase II program were:

- Reduce the time required to taper the track by allowing in situ rail adjustment.
- Improve the accuracy of the rail positioning and taper.
- Provide a method for verifying the rail position while the sections are installed in the track.

GUIDELINES AND ASSUMPTIONS

- The amount of permanently mounted hardware for the rail support and adjustment mechanism must be kept to a minimum to allow maximum access to the track for experimental apparatus.
- Access is available to the track sections along the entire length of the 200-foot-long taper section.
- The system cannot require replacement of the existing support tubes and rails.
- Modifications to the existing support tubes and rails are acceptable, but should be minimized.

- The maximum spacing between rail supports is 18 inches.
- Mechanisms that will be installed in G-Range should not require lubrication.

PERFORMANCE REQUIREMENTS

This program had the following specific performance requirements:

- A new track taper can be implemented with less than 48 man-hours of effort.
- The rails must be kept concentric with the support tube inside diameter within a tolerance of ±0.002 inch.
- The proper rail diameter must be maintained along the entire taper section to within ±0.002 inch.
- The rails must be positively locked in place so that no rail movement is allowed during track shots.

PROGRAM OVERVIEW

To accomplish the tasks of calculating, adjusting, and verifying rail position, the tapering system developed in Phase II is composed of three main subsystems:

- The modified track assemblies
- The rail position gage
- The taper scheduling software

The rail adjuster assemblies (Figure 2) contain the rail within the support tube and provide a range of radial adjustment for the rail. The rail position gage (Figure 3) measures the radial position of the rail with respect to the internal diameter of the support tube. The gage can provide information about the distance between the rails and the centration error with respect to the support tube, or it can report the radial distance from the centerline of the support tube internal diameter and the face of each rail. The taper scheduling software is a stand-alone program that runs on a DOS computer. The software allows the operator to select the entrance and exit diameters for the taper section, and the software will generate the correct rail settings for each adjuster along the length of the taper section.

The tapering system development consisted of the following Phase II program tasks:

1. System Design
2. Prototype Development
3. Final Design
4. Fabrication
5. Assembly and Installation

The preliminary design for the taper system was completed in Task 1. A preliminary design review was held at QUEST Integrated, Inc., and was attended by Captain Dave Burgess and Larry Campbell of AEDC. Based on this review, prototypes of the subsystems were built and tested in Task 2. A final design was prepared in Task 3 and a final review was held at QUEST with Captain Burgess and Larry Campbell. The final design was fabricated, tested, and installed at AEDC.

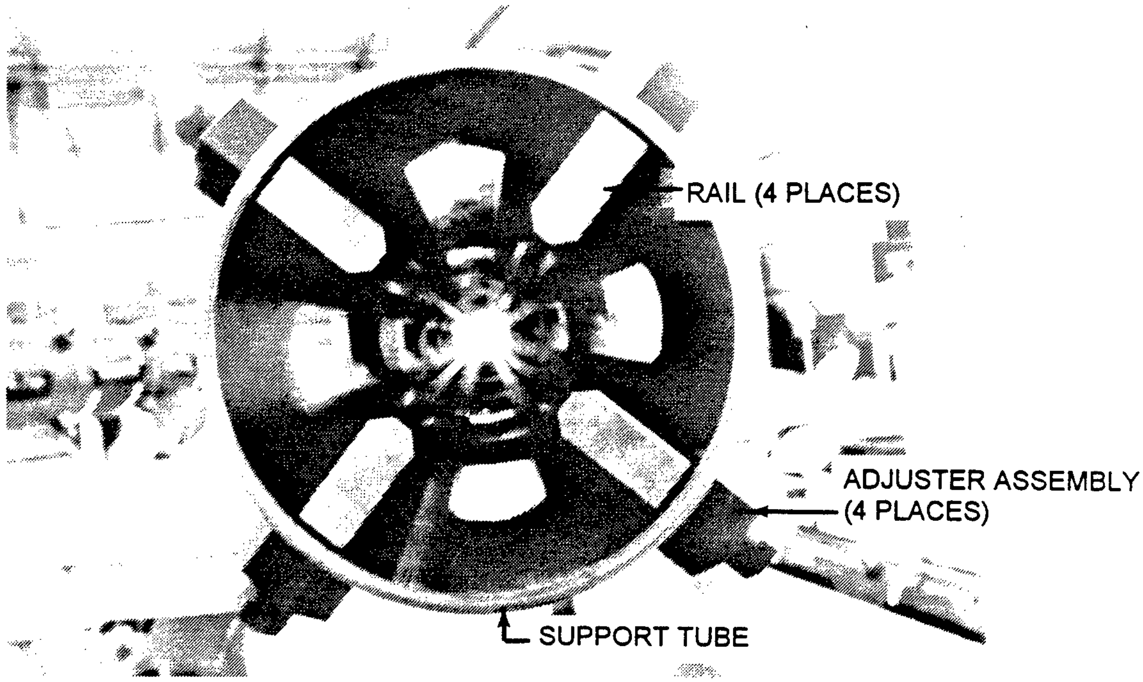


Figure 2. Rail Adjuster System

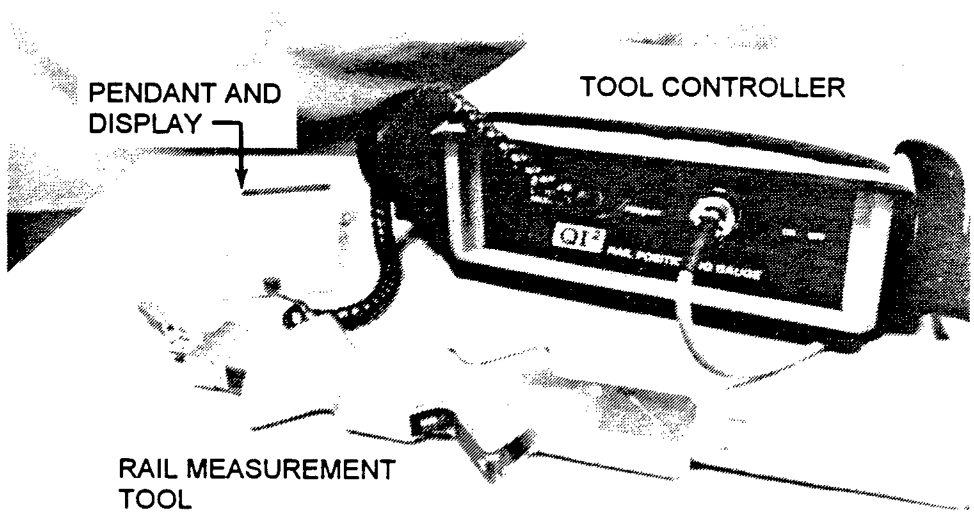


Figure 3. Rail Position Gage

During the course of this program, the G-Range facility at AEDC was being upgraded from a 2.5-inch-diameter to a 3.3-inch-diameter gun and track as part of a another, larger improvement project. The track tapering project was synchronized with this larger track upgrade in order to insure compatibility between the tapering system and the new track. This had no effect on the budget for this program, but it did extend the program duration to three years. However, coordination between the two projects produced a tapering system that is completely compatible with the new track diameter.

DESIGN

The design effort for the track tapering system was carried out in three tasks: System Design, Prototype Development, and Final Design. The following sections present a brief overview of the design and selection process and then present the final system design.

MODIFIED TRACK ASSEMBLIES

This section describes the development of a mechanism to allow radial adjustment of the rail position within the support tube. The first subsection deals with the design of the adjustment mechanism itself, and the second describes the method for determining the number of adjusters required on each support tube.

Adjuster Design

A cross section of the support tube and rails is shown in Figure 4. As indicated by the figure, the two critical dimensions for maintaining the correct track taper are the rail diameter dimension and the rail centering dimension. The rail diameter dimension is the distance between the opposing rail faces. The centering dimension is the concentricity of the rail faces to the internal diameter of the support tube.

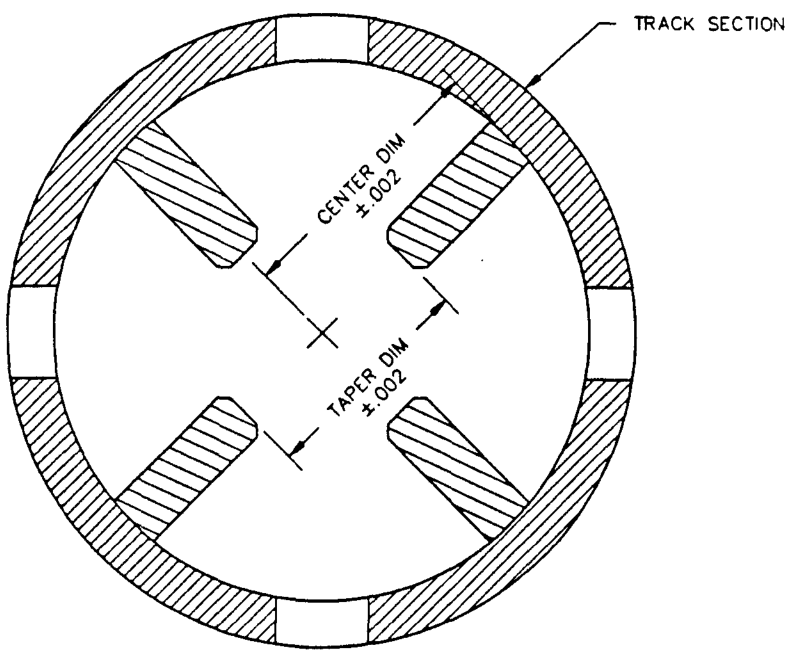


Figure 4. Hypervelocity Test Track Support Tube Assembly

The original track hardware used cap screws to bolt the rails against the internal diameter of the support tube. The cap screws were spaced at approximately 12-inch intervals (axially) along the support tube. The support tube internal diameter was used as a radial reference for the rail position. The existing practice for tapering at AEDC was to place shim stock between the back of the rail and the inside surface of the support tube. This procedure would adjust the rail toward the center of the support tube, reducing the rail diameter. The shimming and measuring of the rails was very time consuming.

The concept for rail adjustment was to replace the cap screws in the support tube assembly with small but very stiff adjuster mechanisms. This would give AEDC personnel the ability to make fine adjustments to the rail position from the outside of the support tube, even while the support tube was installed in G-range. As explained above, the adjusters had to be compatible with the existing support tubes and rails and should only require a minimum of modifications.

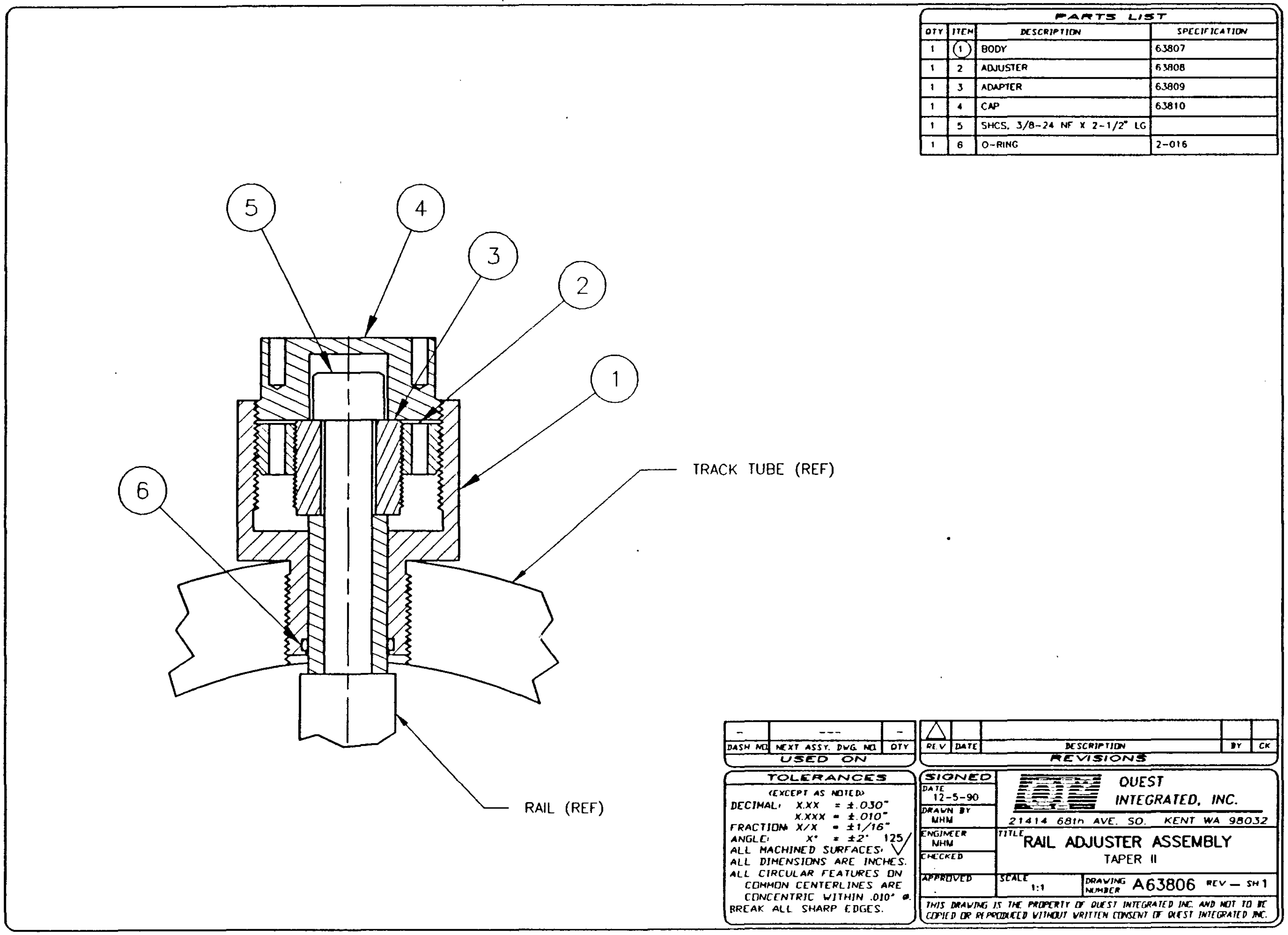
Figures 5 through 8 show four of the concepts that were developed and tested during this program. All of these designs incorporate the following features:

- The existing cap screw holes on the support tube are enlarged and threaded to accept the adjuster body.
- A hexagonal-shaped adjuster body threads into the support tube.
- A cap screw passes through a bushing and then threads into the existing holes in the rail.
- The bushing is a precision fit in the bore of the adjuster body, creating a radial slide mechanism for the rail.
- An o ring seals the bottom of the adjuster so that track debris cannot contaminate the bore of the adjuster.
- The clearance between the cap screw and the I.D. of the bushing allows some adjustment at assembly for variations in the spacing of the adjuster bodies in the support tube and the tapped holes in the back of the rail.
- A screw mechanism is provided to radially position the rail with respect to the adjuster body.

The adjuster design, shown in Figure 5, incorporates a differential screw mechanism to allow very fine adjustment of the rail position. A pin spanner wrench was used on both the cap and the adjuster nut. The principal drawback of this design was that the cap had to be removed to access the adjuster nut. When the cap was replaced and locked down, the adjustment would typically change by a small amount.

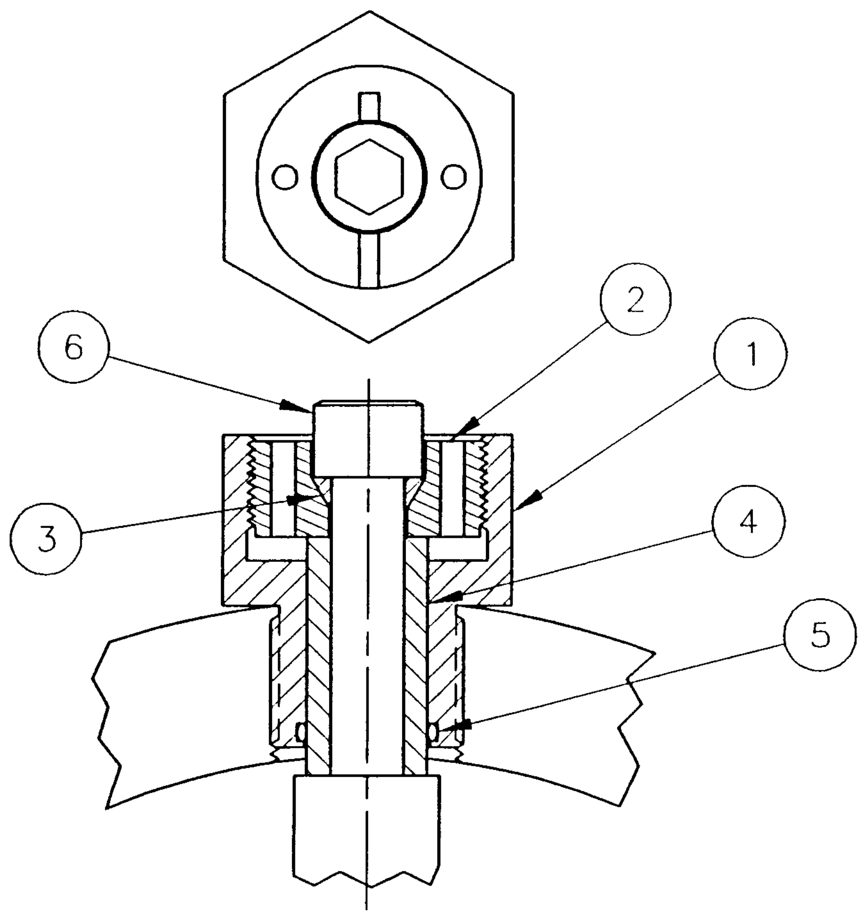
The design in Figure 6 used a split adjuster nut for a locking feature. Tightening the center cap screw drives the cone-shaped collar into a taper on the inside of the adjuster nut, which expands the nut against the threads of the adjuster body. This worked well because it removed all the clearance from the adjuster nut threads, creating a very stiff assembly. The drawback of this design was that the center cap screw had to be loosened to adjust the rail taper position. An undesired side-effect of loosening the cap screw was that the rail could shift and change its clocking position with respect to the other rails. Although unlikely, it is possible that with this design the rails could be matched in radial position, but unmatched in clocking position at the joint between two support tube assemblies. Consequently, the development effort concentrated on finding a design that decoupled the adjustment locking feature from the center cap screw.

To prevent the interaction between the locking mechanism and the adjustment, a new clamping feature was incorporated, as shown in Figure 7. As with the first design, a differential screw is used to provide a very fine adjustment for rail radial position. A split clamp is used to grip the bushing with respect to the adjuster body. A prototype of this design showed that the clamp was not very stiff and could not sustain a large radial force on the rail. This was seen as a serious drawback, because the forces imposed on a rail by a glancing blow from a projectile have never been measured and could be quite large.



QTY	ITEM	DESCRIPTION	SPECIFICATION
1	1	BODY	63807
1	2	ADJUSTER	63808
1	3	ADAPTER	63809
1	4	CAP	63810
1	5	SHCS, 3/8-24 NF X 2-1/2" LG	
1	6	O-RING	2-016

Figure 5. Rail Position Adjuster - First Design



PARTS LIST			
QTY	ITEM	DESCRIPTION	SPECIFICATION
1	1	BODY #2	63846
1	2	ADJUSTER #2	63847
1	3	COLLAR	63848
1	4	BUSHING, 5/8 O.D. X 1-1/4 LG	13/32 I.D.
1	5	O-RING	2-016
1	6	SHCS, 3/8-24 NF X 2" LG	---

DASH NO	NEXT ASSY. DWG NO.	QTY.
-	---	-

USED ON

REV	DATE	DESCRIPTION	BY	CK

REVISIONS

TOLERANCES
(EXCEPT AS NOTED)
DECIMAL: X.XX = ±.030"
X.XXX = ±.010"
FRACTION: X/X = ±1/16"
ANGLE: X° = ±2°
ALL MACHINED SURFACES: 125
ALL DIMENSIONS ARE INCHES.
ALL CIRCULAR FEATURES ON COMMON CENTERLINES ARE CONCENTRIC WITHIN .010" ⌀
BREAK ALL SHARP EDGES.

SIGNED
DATE 12/5/90
DRAWN BY MHM
ENGINEER MHM
CHECKED
APPROVED

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TITLE RAIL ADJUSTER #2
TAPER II

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Figure 6. Rail Position Adjuster - Second Design

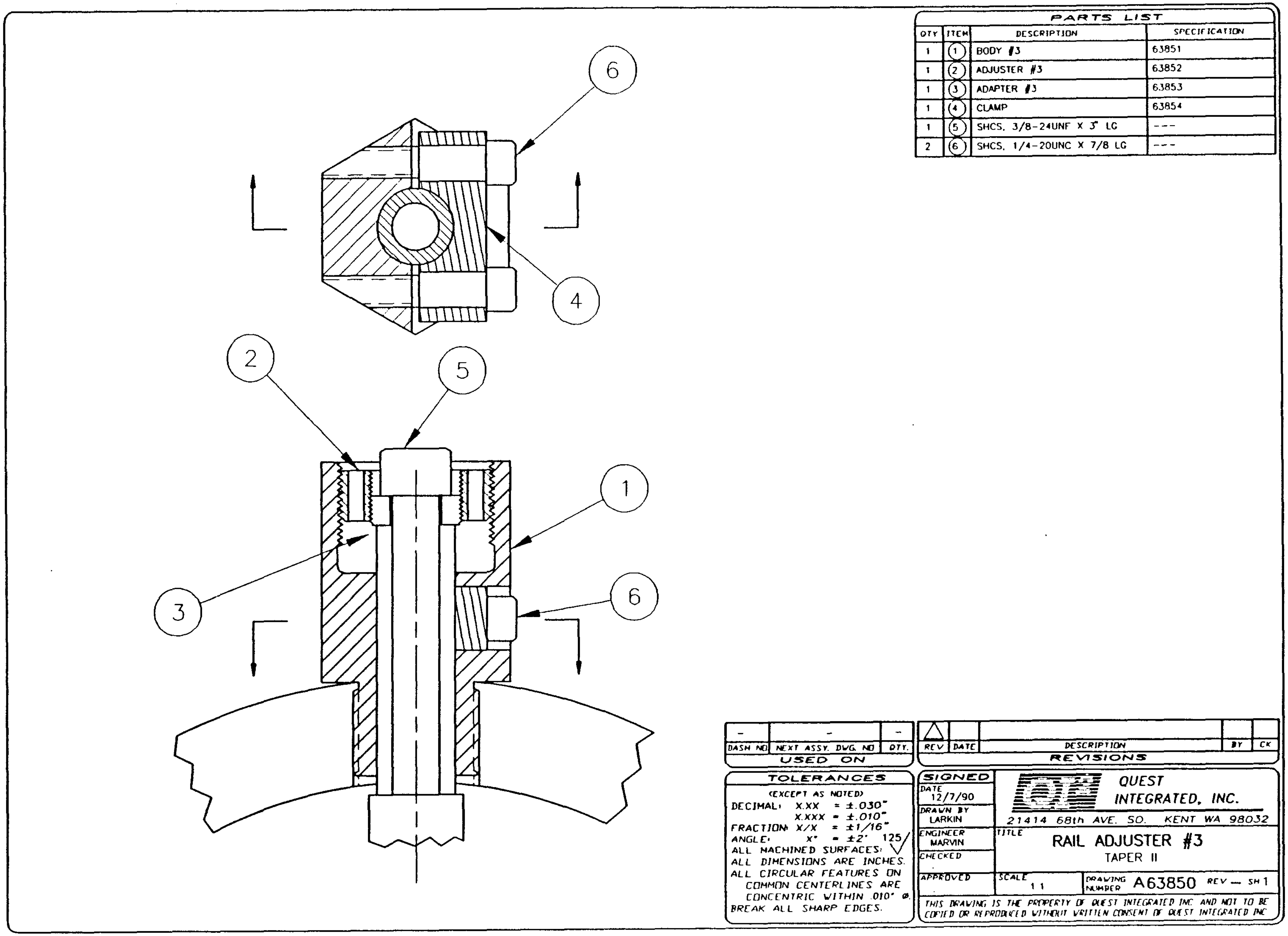
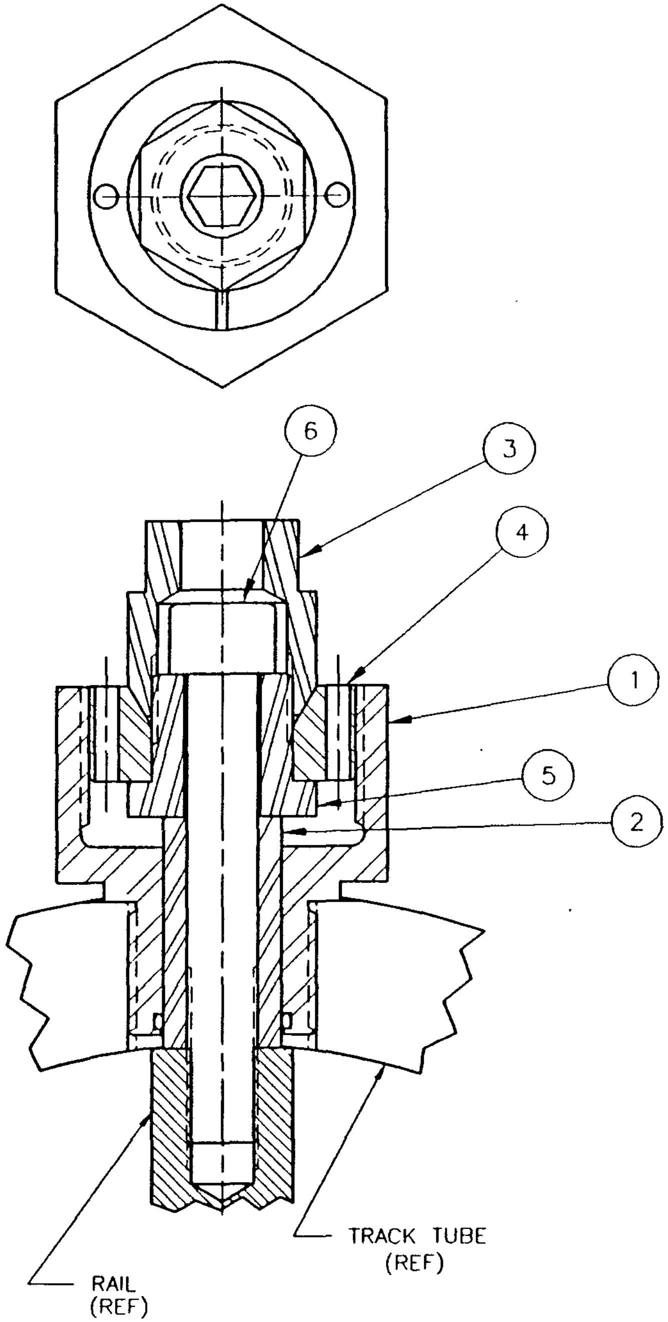


Figure 7. Rail Position Adjuster - Third Design



PARTS LIST			
QTY	ITEM	DESCRIPTION	SPECIFICATION
1	1	BODY #4	64252
1	2	BUSHING	64253
1	3	LOCK NUT	64254
1	4	ADJUSTER #5	64257
1	5	ADAPTER #5	64258
1	6	SOC HD CAP SC, 3/8-24 X 2.5	

DASH NO	NEXT ASSY. DWG. NO.	QTY.
-	-	-

USED ON

REV	DATE	DESCRIPTION	BY	CK

REVISIONS

TOLERANCES
(EXCEPT AS NOTED)
DECIMAL: X.XX = ±.030"
X.XXX = ±.010"
FRACTION: X/X = ±1/16"
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ALL MACHINED SURFACES: 125
ALL DIMENSIONS ARE INCHES.
ALL CIRCULAR FEATURES ON COMMON CENTERLINES ARE CONCENTRIC WITHIN .010"
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ENGINEER MHN
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TITLE RAIL ADJUSTER #5
TAPER II

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Figure 8. Rail Position Adjuster - Final Design

The final design for the adjuster is shown in Figure 8. This approach is a hybrid of the previous designs. A center cap screw is used to preload the bushing and an adapter against the back of the bolt. The cone-shaped locknut draws the adapter against the underside of the split adjuster nut and simultaneously expands the nut against the threads in the adjuster body. There are several advantages to this design:

- The cap screw is tightened during the setup process to establish the rail clocking and is not used during the taper adjustment process.
- The adjustment system allows simultaneous access to both the adjuster nut and the locknut.
- The locknut removes any clearance in the mechanism, so there is negligible hysteresis in the position of the rail after adjustment.

Adjusting the rail position is very simple for this design. A pin spanner wrench is used to rotate the adjuster nut, and a standard box-end wrench is used on the locknut. The two are slightly preloaded against each other to remove any clearance and then rotated together to change the rail position. When the desired position has been reached, the adjuster nut is held fixed while the locknut is tightened. Although this adjuster does not incorporate a differential screw, the resolution was found to be satisfactory. This design also allows the entire assembly to be removed and replaced without removing the track section and rail from G-Range.

All of the above adjuster designs were tested for their stiffness and hysteresis. This was done because the forces incurred during a projectile strike on the rail could be substantial. A simple test setup was used on a hydraulic press to determine the deflection of the rail with respect to the support tube when radial forces are applied to the rail. Forces from 1000 to 5000 pounds were applied, and the change in the location of the cap screw and bushing with respect to the adjuster body were recorded. The results of these tests are shown in Figure 9. Clearly, the chosen design matches the best stiffness and least hysteresis of any of the designs. The lack of stiffness and hysteresis of the side clamp model is also evident. From the graph, the value of preload within the mechanism and an integral locking mechanism were apparent. The final design blended the best characteristics of the previous efforts.

Adjuster Spacing

Another aspect of the rail support was to determine the axial spacing of the adjusters along the support tube. As described above, the existing support tubes used cap screws on approximately 12-inch spacing to secure the rails. Some compromise had to be found between providing adequate support for the rail but not overconstraining the rail so that taper changes caused binding between the adjusters. This decision was complicated by a lack of information about the forces seen by the rail during a glancing blow from a projectile during a G-Range test shot. The experience at G-Range is that the 12-inch spacing has always been adequate, but a few sections have operated with as much as 36-inch spans between the rail supports. Because the projectile impact forces could not be easily modeled, tests were performed to compare the new rail support system with the existing system at G-Range.

Using the actual rail and adjuster hardware, a test program characterized the trade-offs between the net rail stiffness and the adjuster spacing. These two qualities were chosen as good predictors for the behavior of the support system under actual use. The plan for this test program is given in Appendix A. The results are presented in Appendix B. Two basic types of tests were performed in this effort:

- The static stiffness of the rail and supports was measured at mid-span for several different support spacing.
- The natural frequency of the rail was measured for different support spacing.

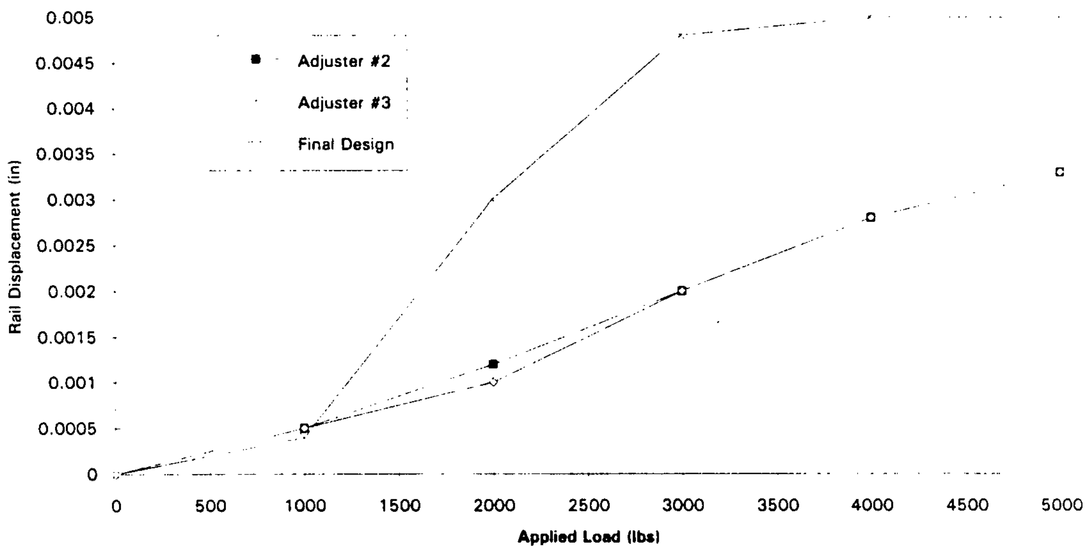


Figure 9. Adjuster Stiffness Test Results

Based on these tests, an adjuster spacing of 18 inches was chosen. This spacing was a good compromise between overconstraining the rail and yet not deviating too far from existing track experience. In addition, it left open the future possibility for the G-Range personnel to release every other adjuster to allow supports on a 36-inch spacing.

RAIL POSITION GAGE

This section describes the development and testing of a measurement tool to determine the position of the rails within the support tube. Previously, these measurements were taken by hand using telescoping gages and outside micrometers. To reduce the time required to make a taper adjustment, a new gaging system was needed.

The original Phase II proposal was based on using a commercial electronic test indicator that would measure the position of the back of the rail with respect to the support tube. However, after some review with AEDC personnel during Phase II, it was apparent that a more direct measurement system was needed. The rail position gage (Figure 10) answers this need. The gage is composed of the following major subsystems:

- The rail measurement tool, which measures the rail positions within the support tube.
- The tool controller, which houses the support electronics for the measurement tool.
- The pendant and display, which provides the readout for the operator.

The purpose of the rail position gage system is to determine the position of the rail faces with respect to the centerline of the support tube. This requires the simultaneous measurement of the support tube internal diameter and the positions of each rail face with respect to one side of the support tube. Figure 11 shows a schematic of this method. Three measurement devices are suspended in the support tube. Device number

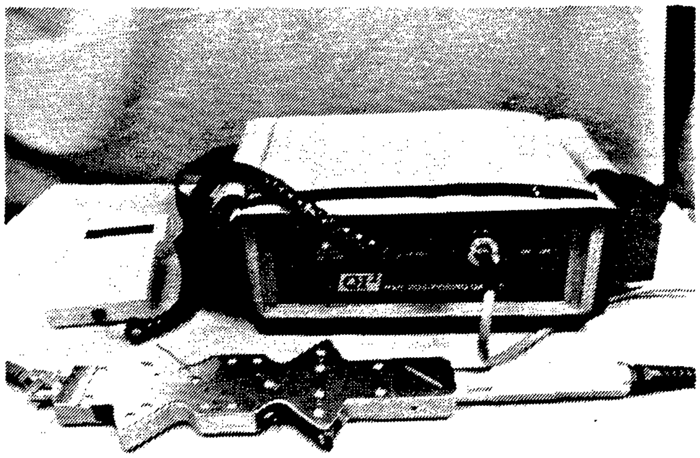


Figure 10. Rail Position Gage

three is grounded on the left side of the support tube I.D., and it measures the distance to the right side of the support tube I.D. The measurement is positive in the direction of the device arrow. Devices one and two are attached to device three and measure the positions of the rails with respect to the body of device three. As shown in Figure 11, with proper calibration the positions of the rails can be determined in two different ways:

- The distance from the actual centerline of the support tube to each rail face can be computed. These results are called the rail radii.
- The distance between the rails, and their concentricity with respect to the actual centerline of the support tube, can be computed. These results are called the rail diameter and centering error.

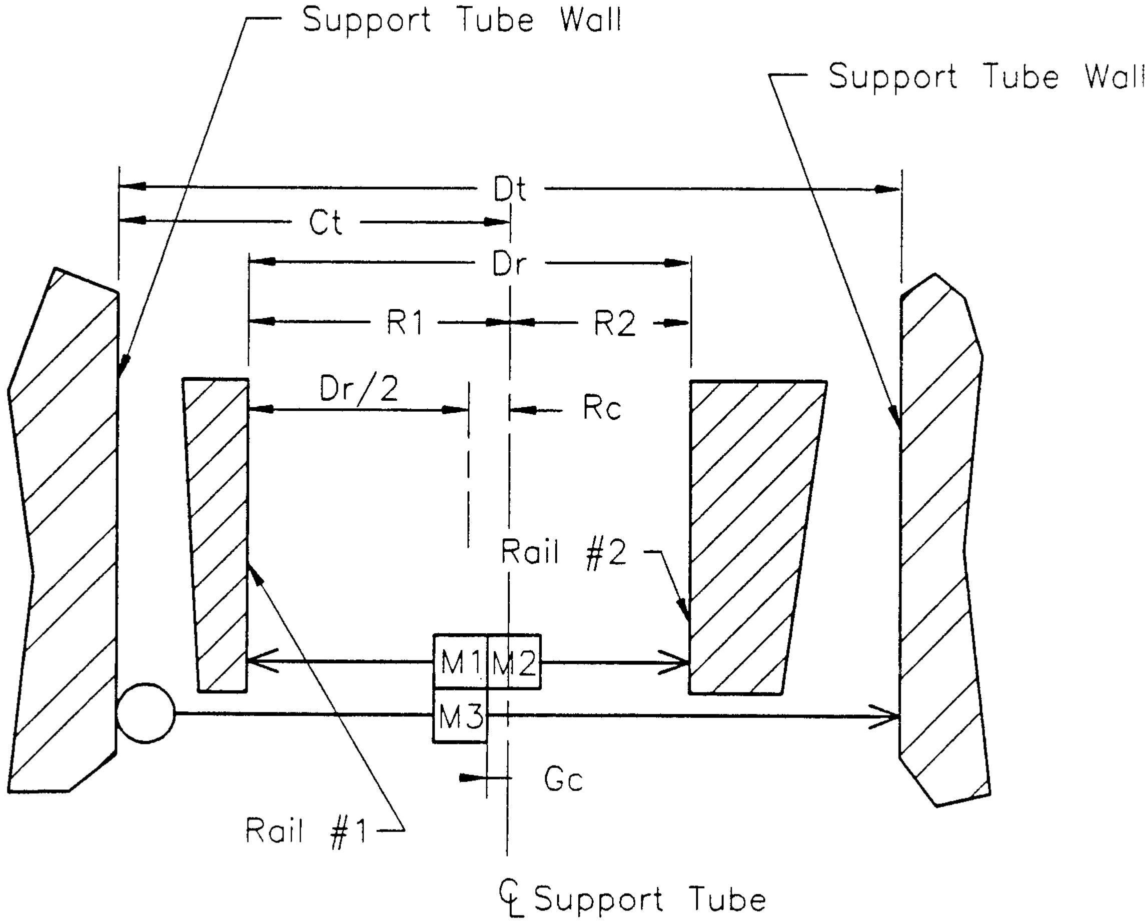
To implement this approach required choosing the proper sensors, packaging the electronics, developing the calibration system, and building a display and user interface. The following subsections describe the concept, development, and testing of the rail position gage system.

Rail Measurement Tool

The measurement tool houses the position sensors and provides the stable reference surfaces and locating features for placement in the support tube. Figure 12 illustrates the original concept for the tool. A flat, paddle shape is used so that the tool can be inserted through the existing slots in the support tube. Once inserted, it is rotated 90 degrees to engage the reference surface against the tube wall and the measurement devices against two rails and opposing tube wall. To measure the other two rails, the tool is rotated 180 degrees around its handle.

This concept required the sensors to be small enough to be packaged into a 1-inch-thick tool, and yet have sufficient travel to accommodate the range of tapers desired in the track. The following ranges and accuracies were required:

The rail position measurement ranges were determined from the total taper range of 3.3 to 3.1 inches. The accuracy was based on the "gage makers rule" of using a sensor that is ten times the accuracy of the requirement to locate the rails within ±0.002 inch. The range of measurement for the tube diameter sensor



D_t = Tube Diameter = M3 + 7.000

$$C_t = \frac{D_t}{2} = 3.5 + \frac{M3}{2} = 3.5 + G_c^*$$

R1 = Rail #1 Radius = M1 + G_c

R2 = Rail #2 Radius = M2 + G_c

D_r = Rail Diameter = M1 + M2

R_c = Rail Centering Error = $G_c + \dfrac{M1 - M2}{2}$

*For a 10-degree angle between the line of action between M1 - M2 and M3: $G_c = \dfrac{M3}{2} \cdot \dfrac{\cos(45)}{\cos(35)}$

Figure 11. Rail Position Measurement Schematic

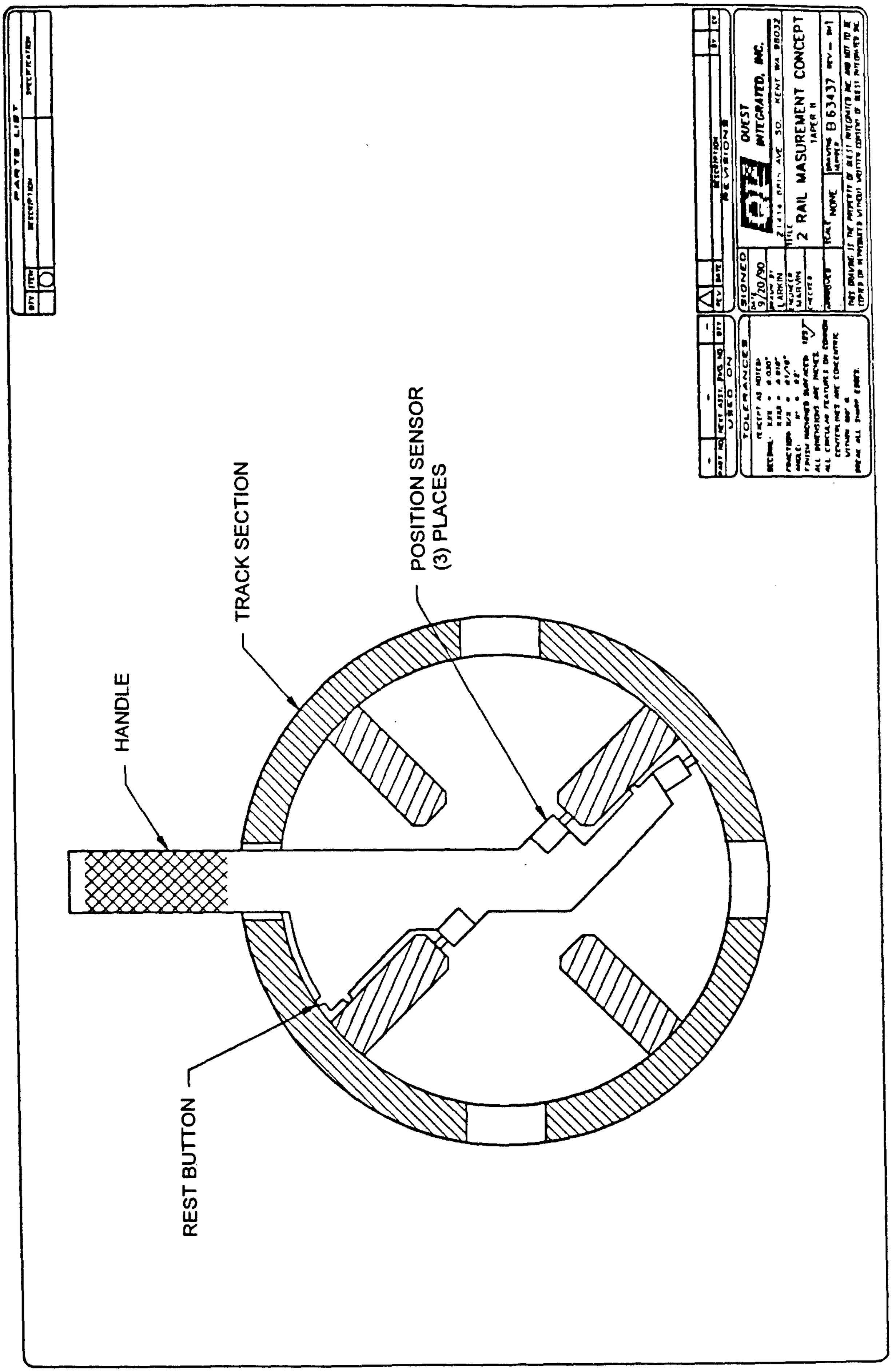


Figure 12. Measurement Tool Concept

Table 1. Rail Measurement Tool Requirements

Measurement	Range	Accuracy
Rail Position	0.100 inch	±0.0002 inch
Tube Diameter	0.020 inch	±0.0002 inch

was based on allowing a generous margin above the print tolerance for the internal diameter. This would allow the gage to accommodate possible deformation in the support tubes due to use in the G-Range track.

After consideration of several different sensing technologies, linear variable differential transformers (LVDTs) were chosen for the following reasons:

- The small package size for the transformer portion of the sensor fits within the envelope of the tool.
- The operating ranges are satisfactory for this application: ±0.05-inch linear range, ±0.07-inch operational range.
- The accuracies are 0.3-percent linearity over ±0.05-inch range, which is ±0.00015 inch.
- The sensors are absolute rather than incremental measurement devices. This means that calibration is not required during system power-up.
- The sensor and driver electronics are commercially available items.
- The power consumption is sufficiently low to permit battery power to be used for the gage system.

The LVDTs were designed into a final measurement tool. Figure 13 shows the outline of this tool with the sensors in place. The reference surface is forced against the bottom side of the support tube by the toggle clamp at the top of the tool. Note that the line on the handle of the gage indicates which pair of rails are being measured. By rotating the gage 180 degrees about the centerline of the handle, the opposing rails can also be measured. When in place, the diameter sensor measures on a slightly different diameter than the rail sensors. This is compensated in the electronics and is explained in Appendix C.

Measurement Tool Controller

The rail measurement tool and LVDT sensors are the data acquisition portion of the rail position gage. However, this data must be converted to terms that are useful to the operator. To accomplish this, the tool controller was developed. Taken as a whole, the rail measurement tool, pendant, and controller comprise the rail position gage system. The functions of the tool controller are:

- Supply the power for the system.
- House the support electronics: the signal conditioning electronics for the LVDTs.
- Conversion of the analog signals from the LVDTs to track dimensions in engineering units.
- Perform the calibration functions.
- Provide the operator interface: display track dimensions and operation menus.

To implement the functions for this tool controller, the design shown in Figure 14 was developed. The basic elements of the tool controller are: the sealed battery, the DC converters, the LVDT modulators/demodulators, the analog scaling circuitry, the Onset embedded computer, and the pendant display. A replaceable, commercial video battery supplies the power for the entire rail position gage. DC-

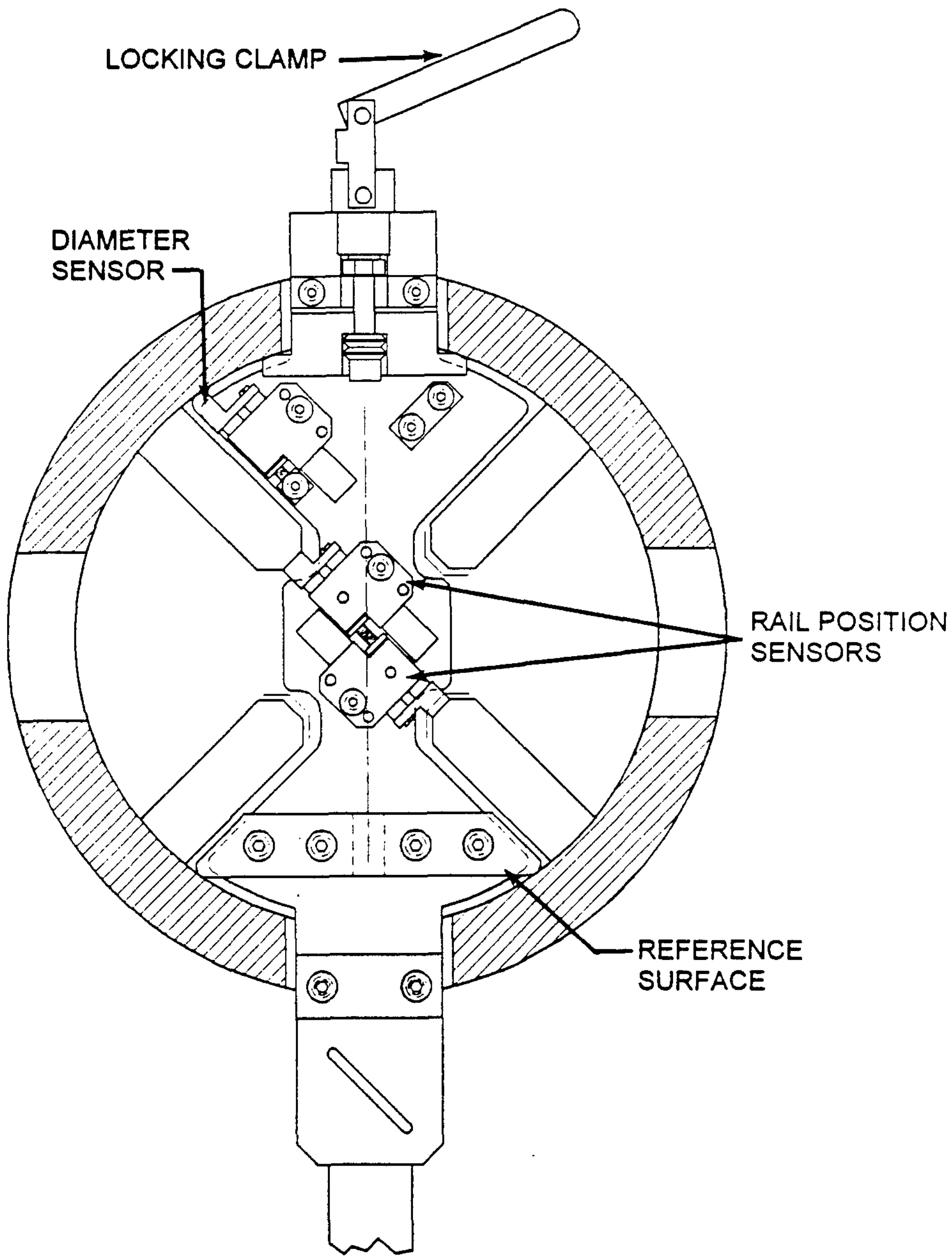


Figure 13. Rail Measurement Tool Layout

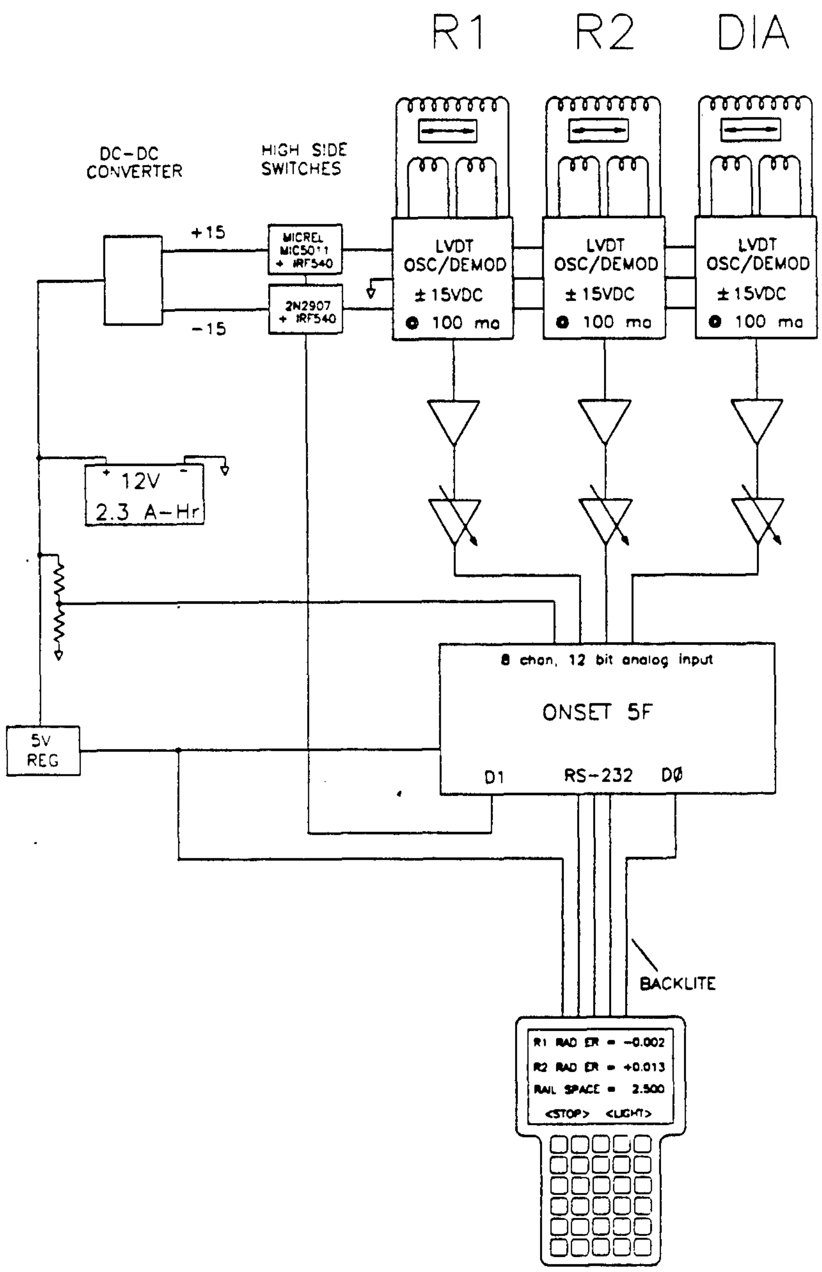


Figure 14. Measurement Tool Controller Block Diagram

to-DC converters are used to generate the appropriate power levels for the LVDTs. Commercial modulator/demodulator modules are used to excite the LVDT coils and convert the return signal to a DC analog voltage. The demodulated LVDT signals are then scaled and thresholded using analog electronics. The signals are then converted by the single-board, Onset model 5F embedded computer, which is based on the Motorolla 6803 processor. Within this computer, the appropriate calibration constants are applied to convert the rail positions to engineering units for display. The hand-held pendant provides the display of rail position information, as well as providing menus for system calibration and battery life.

When considering the power source for the controller, it was important to keep the system as portable as possible. Although AC power is available within the track, the use of extension cords was undesirable. In order to determine whether a portable power source could be used, a model of the power consumption for the system was developed. The two largest consumers of power in the system are the LVDT electronics and the backlight for the pendant displays. It was found that if all of these systems are continuously powered, the operating time for the system with a commercial battery was only two hours. This was not considered to be adequate. To extend the subsystem operation, the LVDT electronics are switched so that they are powered for a 15% duty cycle. This is accomplished by using the embedded computer to switch the LVDT power on, wait for the signal to stabilize, read the LVDT sensor positions, and then switch the LVDT power off. By using this technique, the operational life of the system was extended to 12 hours. This duration provides sufficient margin to allow a battery to be used for one shift of operation.

Initially, the pendant backlight was also going to be switched. This function would mimic desktop calculators that automatically power-down after a certain time if no keys are pressed. Unfortunately, it was not possible to power cycle the backlight without sporadically resetting the pendant, which results in loss of communication with the controller. Consequently, this function was not implemented in the final system. Despite this, the gage operating time is sufficient for operation at G-Range.

The embedded computer was chosen to minimize the power consumption. Although other small systems were surveyed, it was found that the Onset model 5F had the lowest power consumption when all the functions, such as the analog-to-digital conversions, are considered. This computer is commonly used in remote data logging applications and features built-in, analog-to-digital conversion as well as single-contact binary input and outputs. In addition, a built-in EEPROM is provided that allows storage of calibration constants, system serial number, and some diagnostic information. The Onset is programmed for this controller using TXBasic, which is a variation of the BASIC programming language.

All of the electronics in the controller are mounted on a single, custom PC board. This approach allows easy diagnostics and replacement of the system should there be a failure. The PC board was designed by QUEST and fabricated by a local vendor. Spares of the bare board are available at QUEST.

The pendant is a commercial product from Two Technologies, Inc. This hand-held unit has a full keyboard and a four-line display. Figure 15 shows a close-up of the main menu for the display. Only the top four function keys are used for operating the system. As shown, the main menu allows the operator to choose the rail data, perform simple diagnostics, or calibrate the system. The rail display formats are either as the radius distance for each rail or as the rail spacing and centering error. The diagnostics display outputs the raw LVDT voltages. This display is useful for troubleshooting the system, but is not used by a typical operator. The calibration display guides the operator through the sequence of steps to perform a periodic calibration. This function is discussed in greater detail in the next section.

All of the controller electronics are housed in a single box, which is small enough to be carried by one operator using the soft case and shoulder strap. The front panel of the controller box provides the

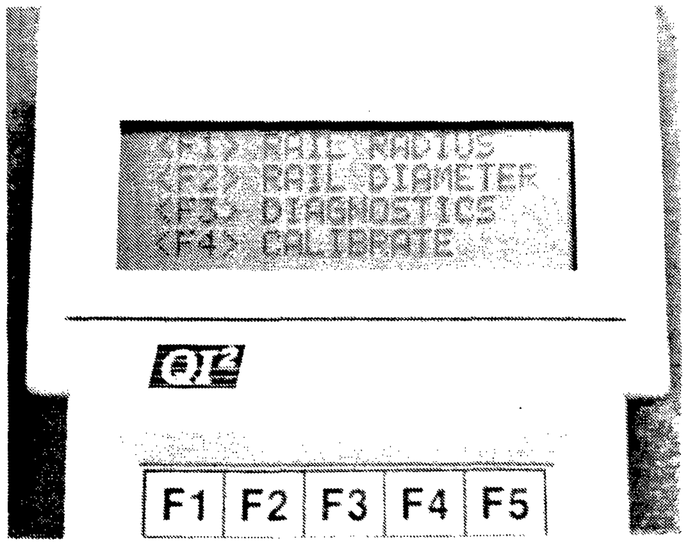


Figure 15. Main Menu Display

connections for the measurement tool, pendant, and access to the battery. Two complete rail position gage systems were delivered in this program, and the measurement tool connectors are keyed to their respective tool controller. This is necessary because the tool controller contains the calibration constants that are particular to a measurement tool. With the keyed connectors a measurement tool cannot be connected to the wrong controller.

Rail Gage Calibration

The LVDT sensors in the rail position gage are very linear, stable devices for measuring position. To convert the analog voltage output of the LVDTs requires establishing two parameters for each sensor: the slope and intercept of the line describing voltage output as a function of the displacement of the sensor core. The slope of each sensor was established in a bench-top test using a micrometer and is stored in permanent memory in the tool controller. These slopes have proven to be very stable and do not need periodic adjustment. With only the slope information, the system can accurately report changes in the rail position but not the absolute position of the rail. Absolute position reporting also requires knowing the intercept point for each sensor.

To establish the absolute accuracy of the rail position gage, a master calibration fixture was constructed and certified. Figure 16 shows the calibration fixture with a measurement tool installed. The calibration fixture accurately simulates a support tube with two rails installed. The fixture's internal diameter and rail positions are accurately known and are stored in the permanent memory of the controller. To calibrate a tool, it is placed in the fixture and the calibration menu option is chosen from the main menu. The software will automatically read the gage positions, calculate the new sensor intercepts, and store them to permanent memory. This procedure is recommended on a periodic basis, such as at the start of each new track taper adjustment.

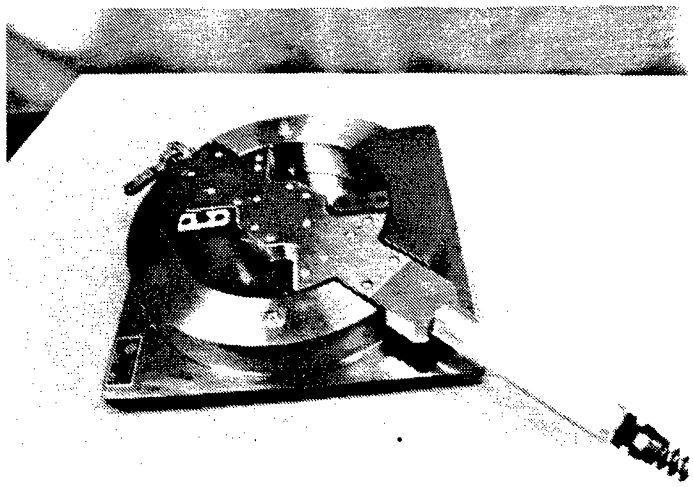


Figure 16. Rail Position Gage Calibration Fixture

TAPER SCHEDULING SOFTWARE

The taper scheduling software is used to calculate the nominal rail positions given a desired track taper. Specifically, rail position at each adjustment point is calculated with respect to the internal diameter of the support tubes based on starting and ending rail diameters. It was recognized early in the program that if the rail adjuster spacing was 18 inches then approximately 130 adjustment settings would have to be calculated for each desired taper. Clearly, this would be best accomplished using a desktop computer. The key elements of the software design task were:

- The degree of versatility in the program: what lengths of track could be used for the taper and how many different tapers could be specified?
- The features for the user interface: what terminology and format would minimize the level of effort and training required to use the system?
- The program output format: what information was most useful for implementing and checking a taper, and how should it be presented?

The initial concept for the scheduling software would support only one uniform taper over all 20 track sections. However, after reviewing the approach with AEDC personnel, it became apparent that multiple tapers may be desired in the future and the software should be written to accommodate this feature. Based on this, a user interface, similar to a computer spreadsheet, was developed. This interface is shown in Figure 17. Up to four different tapers can be specified: one row is used for each taper. The columns represent the starting location of the taper, the starting diameter, the ending location of the taper, and the ending diameter. The slope of the taper is calculated automatically based on the input. The locations are specified by unit number, which is clearly marked on the support tubes in the track. The spreadsheet checks the input to verify that the starting and ending locations are contiguous and not repeated. A help screen is available to assist the operator.

TRACK TAPERING SYSTEM INPUT SCREEN

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Group	From Entrance of Unit #	Entrance Diameter	To Exit of Unit #	Exit Diameter	Rail Slope
1	-----------	-----------	-----------	-----------	n/a
2	-----------	-----------	-----------	-----------	n/a
3	-----------	-----------	-----------	-----------	n/a
4	-----------	-----------	-----------	-----------	n/a

Name: --------------------------

Text: --

Home End Ins Del – ⟨Ctrl⟩– Esc ↵ Tab ⟨Shift⟩Tab
⟨Alt⟩Help ⟨Alt⟩Print ⟨F1⟩Recall

v2.0 INS-OFF

Figure 17. Taper Scheduling Software User Interface

The format of the output is a worksheet for the craftsmen to use while making the adjustments or inspecting the final results. The radius scheduling sheet (Figure 18) provides the operator with a checklist to use during adjustments. Each row on the worksheet corresponds to a unit number, or support tube. Each column represents the rail radius for an adjuster location. Seven radii in each row correspond to the seven adjusters on each support tube. A column is provided next to each adjuster set point for the operator to check off. Note that some unit numbers have multiple rows to allow a rough adjustment before the final adjustment. When a large adjustment is required, multiple adjustment steps protect the mechanisms from binding and make the adjustment more consistent.

The diameter reference sheet is shown in Figure 19. This sheet is similar to the radius schedule, but it is used to verify the adjustments after the taper has been set in the track. The diameter reference is used in conjunction with the diameter display on the rail gage. The rail settings can be quickly compared with the reference sheet and verified or corrected.

INTEGRATION AND TESTING

The Track Tapering System was fabricated and integrated at QUEST. This section discusses the integration process and the final testing of the system.

MODIFIED TRACK ASSEMBLIES

The support tubes and rails were shipped from AEDC to QUEST for modification and assembly. This approach was chosen because it posed the least risk to the equipment during modification. The rails were not modified, but the support tubes were modified to accept the new adjuster assemblies. By making the modifications near QUEST, the machining operations could be more closely supervised.

The completed support tubes were inspected and stored at QUEST. The adjuster assemblies and rails were installed to form completed track sections. The sections were tested to insure that the complete range of adjustment was possible on each rail. The sections were then shipped back to AEDC in advance of the installation trip.

RAIL POSITION GAGE TESTS

The rail position gages were assembled at QUEST and then debugged and verified for proper function. Several revisions of the embedded software were tested as the functionality of the system was exercised and improved. When the gages were completed, the calibration fixture was used to verify the performance. The gage was placed in the fixture and shim stock was used to change the apparent values for the support tube diameter and rail positions. The resulting readouts were compared with the known correct values. The results of this test were all within the required ±0.002-inch accuracy.

The rail position gages were also tested by symmetry on the calibration fixture. In this test, the tool is inserted in the fixture, and the readings are recorded. The tool is then flipped 180 degrees about the centerline of the fixture, so that the tool bottoms against the opposite side of the fixture, and the rail position sensors swap rails for measurement. The readings before and after the swap were compared and found to be within ±0.0005 inch. This test was repeated on actual tube sections and found to be repeatable to within ±0.001 inch in most cases and always within ±0.002 inch.

QI² - RADIUS SCHEDULING SHEET

```
Log Date     : 02-24-1993
Log Time     : 14:48
Group 1 data : 77, 3.3, 96, 3.1
Operator     : Tim Call
Comment      : Max Adj = 0.025 inches (1/2 turn)
```

		downrange -------->													
G	Un	√	Stripe	√	Stripe	√	Stripe	√	Stripe	√	Stripe	√	Stripe	√	Stripe
1	77		1.6495		1.6490		1.6480		1.6475		1.6470		1.6460		1.6455
1	78		1.6445		1.6440		1.6430		1.6425		1.6420		1.6410		1.6405
1	79		1.6395		1.6390		1.6380		1.6375		1.6370		1.6360		1.6355
1	80		1.6345		1.6340		1.6330		1.6325		1.6320		1.6310		1.6305
1	81		1.6295		1.6290		1.6280		1.6275		1.6270		1.6260		1.6255
1	82		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW
1	82		1.6245		1.6240		1.6230		1.6225		1.6220		1.6210		1.6205
1	83		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW
1	83		1.6195		1.6190		1.6180		1.6175		1.6170		1.6160		1.6155
1	84		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW
1	84		1.6145		1.6140		1.6130		1.6125		1.6120		1.6110		1.6105
1	85		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW
1	85		1.6095		1.6090		1.6080		1.6075		1.6070		1.6060		1.6055
1	86		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW
1	86		1.6045		1.6040		1.6030		1.6025		1.6020		1.6010		1.6005
1	87		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW
1	87		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW
1	87		1.5995		1.5990		1.5980		1.5975		1.5970		1.5960		1.5955
1	88		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW
1	88		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW
1	88		1.5945		1.5940		1.5930		1.5925		1.5920		1.5910		1.5905
1	89		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW		0.5CW

Figure 18. Radius Scheduling Sheet

QI² - DIAMETER REFERENCE SHEET

```
Log Date      : 02-24-1993
Log Time      : 14:48
Group 1 data  : 77, 3.3, 96, 3.1
Operator      : Tim Call
Comment       : Max Adj = 0.025 inches (1/2 turn)
```

		downrange -------->													
G	Un	√	Stripe	√	Stripe	√	Stripe	√	Stripe	√	Stripe	√	Stripe	√	Stripe
1	77		3.299		3.298		3.296		3.295		3.294		3.292		3.291
1	78		3.289		3.288		3.286		3.285		3.284		3.282		3.281
1	79		3.279		3.278		3.276		3.275		3.274		3.272		3.271
1	80		3.269		3.268		3.266		3.265		3.264		3.262		3.261
1	81		3.259		3.258		3.256		3.255		3.254		3.252		3.251
1	82		3.249		3.248		3.246		3.245		3.244		3.242		3.241
1	83		3.239		3.238		3.236		3.235		3.234		3.232		3.231
1	84		3.229		3.228		3.226		3.225		3.224		3.222		3.221
1	85		3.219		3.218		3.216		3.215		3.214		3.212		3.211
1	86		3.209		3.208		3.206		3.205		3.204		3.202		3.201
1	87		3.199		3.198		3.196		3.195		3.194		3.192		3.191
1	88		3.189		3.188		3.186		3.185		3.184		3.182		3.181
1	89		3.179		3.178		3.176		3.175		3.174		3.172		3.171
1	90		3.169		3.168		3.166		3.165		3.164		3.162		3.161
1	91		3.159		3.158		3.156		3.155		3.154		3.152		3.151
1	92		3.149		3.148		3.146		3.145		3.144		3.142		3.141
1	93		3.139		3.138		3.136		3.135		3.134		3.132		3.131
1	94		3.129		3.128		3.126		3.125		3.124		3.122		3.121
1	95		3.119		3.118		3.116		3.115		3.114		3.112		3.111
1	96		3.109		3.108		3.106		3.105		3.104		3.102		3.101

Figure 19. Diameter Reference Sheet

TAPER SCHEDULING SOFTWARE TESTS

The taper scheduling software was tested by computing several complex, multiple-section tapers and generating the scheduling sheets. These same tapers were then computed using commercial PC spreadsheet software. The values were cross checked for consistency and accuracy.

DELIVERABLES

The following specific deliverables have been provided as part of the project:

1. A total of 20 modified support tubes with adjuster mechanisms and rails installed. One additional support tube was modified as a spare.
2. Two complete wrench sets for the adjusters.
3. Two complete rail position gage systems. Each system includes:
   - Rail measurement tool
   - Tool controller and pendant
   - Spare battery
   - Battery charger
   - Soft carrying case
   - Hard-shell case for the complete gage set
4. Rail position gage calibration fixture and hard-shell case.
5. Rail squaring tool and hard-shell case.
6. User's Manual for the rail position gage (QUEST TC-378).
7. Taper scheduling software on 3.5-inch diskette.
8. Spare adjuster assembly parts.
9. Modified adjuster wrench sets.
10. Pendant display stands.
11. Final report.

INSTALLATION AND TRAINING

After integration and testing, the track tapering equipment was shipped to AEDC. This was done in advance of the installation trip to allow AEDC adequate time to install the track sections in G-Range. QUEST personnel made one trip to train the AEDC personnel on the use of the tapering equipment.

TRAINING SESSIONS

Two hands-on training sessions were held at AEDC to train the personnel on the use and capabilities of the equipment. The first session was conducted in a shop area and was intended to familiarize the craftsmen with the system components. Six craftsmen participated in this session. A single track section was used for demonstration. During this session, the craftsmen performed the following activities:

- Installation of the adjusters and rails in a modified support tube.
- Squaring, or clocking, the rails with respect to each other.

- Operating the rail position gages.
- Reading and understanding the radius scheduling sheets.
- Setting a taper on the demonstration track section.
- Review of the User's Manual for the rail position gage.

A second training session was held inside of the G-Range Hypervelocity track. During this session, the craftsmen worked in two groups of three to actually set the taper in several sections of the track. At this point, the QUEST personnel provided supervision and guidance only where necessary to give the craftsmen a chance to exercise their skills.

In parallel with these two sessions, the taper scheduling software was installed on a computer in the engineering offices. An AEDC engineer had the opportunity to generate a track taper schedule for use in the second training session.

TRACK TAPER ADJUSTMENT

At the conclusion of the training classes, the QUEST personnel completed setting the track taper in 17 of the 20 track sections. The three remaining track sections were not installed at the time. The track tapering operation was completed by three QUEST engineers using two rail position gages in one and one-half days. During this tapering operation, the following problems were found:

- One track section had a bulge in the diameter of the support tube of about 0.040 inch. This was apparently from previous track damage. QUEST recommended that this track section be replaced.
- In three locations the adjusters were not easily accessed because of track support hardware. Modified adjuster wrenches were recommended.
- The hand-held pendants needed a means for securing them to the track sections during use. Fabrication of clips or other devices was recommended.

At the conclusion of the installation trip, a debriefing session was held with AEDC personnel. It was agreed that QUEST would provide the recommended equipment by the conclusion of the contract.

SUMMARY

In this program, QUEST developed and installed a rapid track tapering system at the Hypervelocity Test Track. Three key subsystems were built: hardware to rapidly adjust the rail positions in the track, a gage to measure the rail positions, and stand-alone software to plan all the rail positions for a desire track taper. The U.S. Government will derive two important benefits from the use of this system:

- Track tapers can be implemented and checked in less time and with fewer resources than the previous system.
- The Hypervelocity Test Track will have improved capability because the track taper can more easily be tailored to the specific conditions of a projectile test.

The system was successfully installed and AEDC personnel were trained in the use and maintenance of the equipment.

APPENDIX A
RAIL TEST PLAN

QUEST Technical Communication No. 334

LABORATORY TESTS FOR THE AJUSTABLE RAIL SUPPORT SYSTEM

M. Marvin

August 1991

Prepared for

ARNOLD ENGINEERING DEVELOPMENT CENTER

Under Contract No. F40600-90-C-0024

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INTRODUCTION

This document outlines the tests that will be performed by QUEST Integrated, Inc., to compare the proposed (adjustable) rail support system with several existing (fixed) rail support systems. These tests are proposed as a substitute for the in-range tests that were originally scheduled. The in-range tests are not possible because of the tight test schedule for the G-Range track.

OBJECTIVE

The objective of these tests is to gather data comparing the proposed support system to the existing support system. This comparison will allow for G-Range Operations to evaluate the performance of the proposed support system, with respect to the existing system, and to approve the new design for implementation in the track.

APPROACH

These tests will evaluate the stiffness and natural frequency of the rails when supported by the alternative systems. The stiffness tests will measure the rail deflection for known loads applied in the radial direction. This measurement will provide an indication of the apparent stiffness of the system during model impacts. The load/deflection tests will be carried out directly over the supports and at intervals between supports.

The natural frequency tests will measure the vibration of the rail in the transverse (radial) direction when excited by a hammer blow. This measurement will provide an indication of the reaction of the system to a model impact. An accelerometer and spectrum analyzer will be used to measure the frequency of the "ringing" of the rail in response to the impulse load.

Several support schemes will be evaluated for comparison. The existing method of bolting the rail to the support tube will be tested at three different nominal spacings: 12 in., 18 in., and 36 in. The proposed actuator design will be tested on an 18 in. (nominal) spacing.

An analysis was performed to better understand rail stiffness and natural frequency for the various support spacings. Values for stiffness and resonant frequency were calculated at intervals and plotted to show trends. Also, the model critical speed was calculated and plotted. The model critical speed is the speed at which the model could potentially induce a resonant vibration in the rail. Lastly, the longitudinal and transverse stress wave speeds for the steel rails were calculated to aid in the understanding of the model/track rail interaction.

Rail Stiffness

The rail can be modeled as a beam supported at a number of regular intervals, as shown in Figure 1a. The load/deflection between supports can be approximated by more simple

models. Deflection of the actual rail will be bounded by the conditions shown in Figures 1b and 1c. Solutions to these conditions are readily found in tables for load/deflection of elastic beams (Shigley, 1977). At the center location, these solutions differ by a factor of four, which is not a very close approximation.

The condition shown in Figure 2 is a better approximation to the actual rail support system. This condition can be solved, using formulas from load/deflection tables and the principle of superposition, to combine two loading cases. This is the solution used to calculate rail stiffness vs spacing. Values calculated using this condition yield load/deflection at a 27% interval between cases 1b and 1c. This is a much more reasonable approximation. Figure 3 is a plot of rail spring rate vs rail spacing. Note that the rail stiffness is inversely proportional to the cube of support spacing. Rails supported on 12-in. centers are about 3.4 times stiffer than those supported on 18-in. centers. Rails supported on 18-in. centers are 8 times stiffer than those supported on 36-in. centers.

Natural Frequency

The formula for the vibration of uniform beam is shown in Figure 4 (Roark, 1982). The first mode of vibration depends only on the node (or support) spacing for a beam with fixed ends and is inversely proportional to the square of the support spacing. Figure 5 shows a plot of the frequency of the first mode of vibration vs support spacing.

Model Critical Speed

If the model were traveling down the track at a speed such that the model was over adjacent midpoints between rail supports in one half a period of vibration, a resonance could be excited. We have called this the model critical speed. This example is not the only condition under which a resonance could be induced, however, in this case, the effect would be the most pronounced. Figure 6 shows the condition used to analyze model critical speed and Figure 7 is a plot of model critical speed vs support spacing.

Table 1 shows the calculated values for rail stiffness, natural frequency, and model critical speed for rail support spacings between 10 and 50 in.

Wave Propagation Speed

As shown above, model speeds are typically many times that of the model critical speed. This section compares model speeds with the rate that information about a collision propagates to the rail supports and downrange along the rail. This information is conveyed as a stress wave. The speed of propagation of a transverse stress wave is slower than that of a longitudinal stress wave. The formulae for the speeds are given below (Timoschenko, 1970). The speed of a

Table 1. Stiffness, Natural Frequency, and Critical Model Speed as a Function of Rail Spacing

87EI= 1.62E+09 LB*IN^2

SQ(EIg/w)= 125000 IN^2/SEC

RAIL SPACING IN	STIFFNESS LB/IN	FREQUENCY Hz	CRITICAL SPEED FT/SEC
10	1621000	1963	3272
12	938079	1364	2727
14	590743	1002	2337
16	395752	767	2045
18	277949	606	1818
20	202625	491	1636
22	152235	406	1487
24	117260	341	1364
26	92228	290	1259
28	73843	250	1169
30	60037	218	1091
32	49469	192	1023
34	41243	170	962
36	34744	152	909
38	29541	136	861
40	25328	123	818
42	21879	111	779
44	19029	101	744
46	16654	93	711
48	14657	85	682
50	12968	79	654

longitudinal wave in steel is about 16,900 ft/s. The speed for a transverse wave in steel is about 10,200 ft/s. Since transverse waves are the ones that could cause rail displacement, which could interfere with the model, they would be of concern. This means that for model speeds above 10,000 ft/s no pertinent information about model/rail impacts could be transmitted down the rail.

$$C_L = (E/\rho)^{1/2}$$

$$C_T = (G/\rho)^{1/2}$$

WORK PLAN

The following section outlines the proposed sequence of tasks for this evaluation.

Test Bed Fabrication

A test has been fabricated to allow mounting the rail with either the existing or the proposed system. This test bed was made by modifying the structural steel angle used for earlier adjuster tests. This shape is approximately 35 times stiffer than the rail. A hydraulic clamping system has been fabricated to allow loads to be applied to the rail at intervals along the track.

Support System Evaluation:

Baseline Tests

Tests will be performed with a rail installed in the track section, on hand at QUEST, to compare test setup to actual setup. A rail will be installed in the 10-ft closed-rail section on 12-in. nominal centers with shims. Loads will be applied using the same jack used on the test bed to establish a baseline for comparing the results found with the test bed. An accelerometer will be attached to the rail and its' natural frequency will be tested to establish baseline data.

Stiffness Tests

Each support system will be implemented on the test bed. Rails will be installed at nominal 12 in., 18 in., and 36 in. spacings using bolts and spacers as fasteners. A dial indicator will be placed so as to measure the displacement between the rail and test fixture. Each rail will be loaded at a midpoint between supports using the hydraulic jack. The deflection for loads between 0-1000 lb, in 100-lb increments, will be recorded. The data will be stored in electronic format and graphed for comparisons with calculated values.

Natural Frequency Tests

Natural frequency will be tested by attaching an accelerometer to the rail and exciting vibration with a hammer blow. The signal from the accelerometer will be fed into a frequency spectrum analyzer to determine the resonant frequency of the rail. The data will be stored in electronic format and graphed for comparisons with calculated values.

Reduction and Reporting

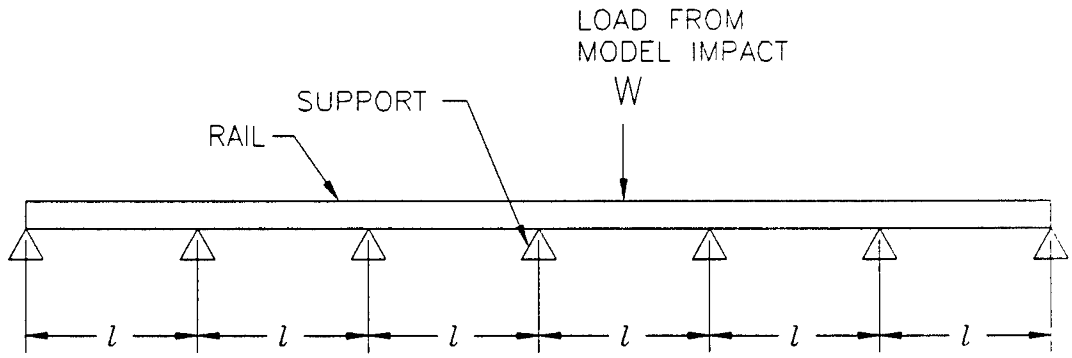
The data will be reduced and evaluated for presentation to G-Range Operations. A brief report will be written summarizing the test procedures, results, and recommendations. Tabular data from the tests performed and plots of the stiffness and frequency data will be included in the report.

REFERENCES

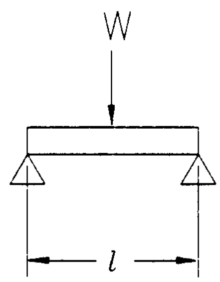
Roark, R. J. and Young, W. C. (1982) *Formulas for Stress and Strain*, McGraw-Hill, New York.

Shigley, J. E. (1963) *Mechanical Engineering Design*, McGraw-Hill, New York.

Timoshenko, S. P. (1970) *Theory of Elasticity*, McGraw-Hill, New York.

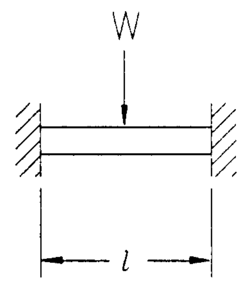


a. Rail with multiple supports



b. Simple supports

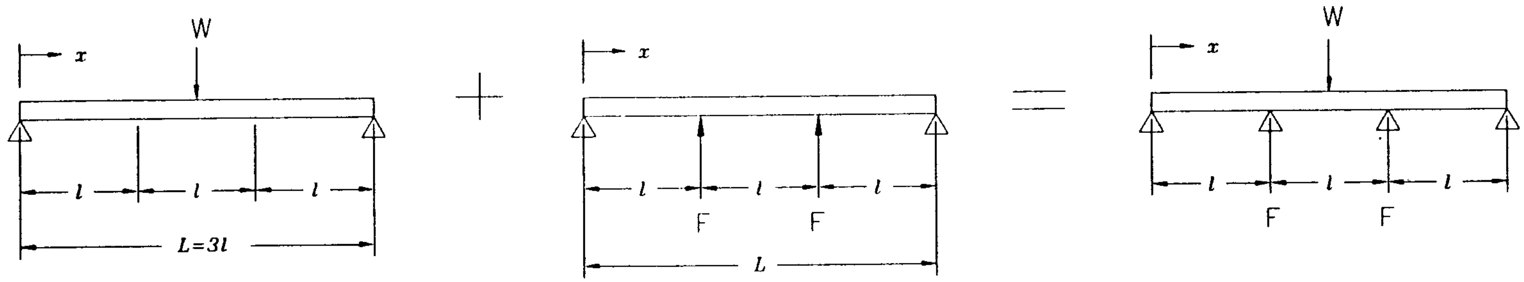
$$\frac{W}{y} = \frac{48EI}{l^3}$$



c. Both ends fixed

$$\frac{W}{y} = \frac{192EI}{l^3}$$

Figure 1. Rail Loading Model



for $0<x<l$ $\quad y = -\frac{Wx}{48EI}(4x^2 - 3L^2)$

or at $x=l$

$$y = -\frac{23\,Wl^3}{48EI}$$

$$y = -\frac{Fx}{6EI}(x^2 - 6l^2)$$

or at $x=l$

$$y = \frac{5\,Fl^3}{6EI}$$

For deflection $= 0$ @ $x=l$

$$\frac{5\,Wl^3}{6EI} - \frac{23\,Fl^3}{48EI} = 0$$

or

$$F = W\,\frac{23}{40}$$

<u>*Center Deflection*</u>

$$y = -\frac{27\,Wl^3}{48EI}$$

<u>*Center Deflection*</u>

$$y = \frac{23\,Fl^3}{24EI}$$

<u>*Center Deflection*</u>

$$y = \frac{23\,Fl^3}{24EI} - \frac{27\,Wl^3}{48EI} = \frac{11}{960}\,\frac{Wl^3}{EI}$$

or

$$\frac{W}{y} = \frac{960\,EI}{11\,l^3}$$

Figure 2. Combination of Cases Using Superposition

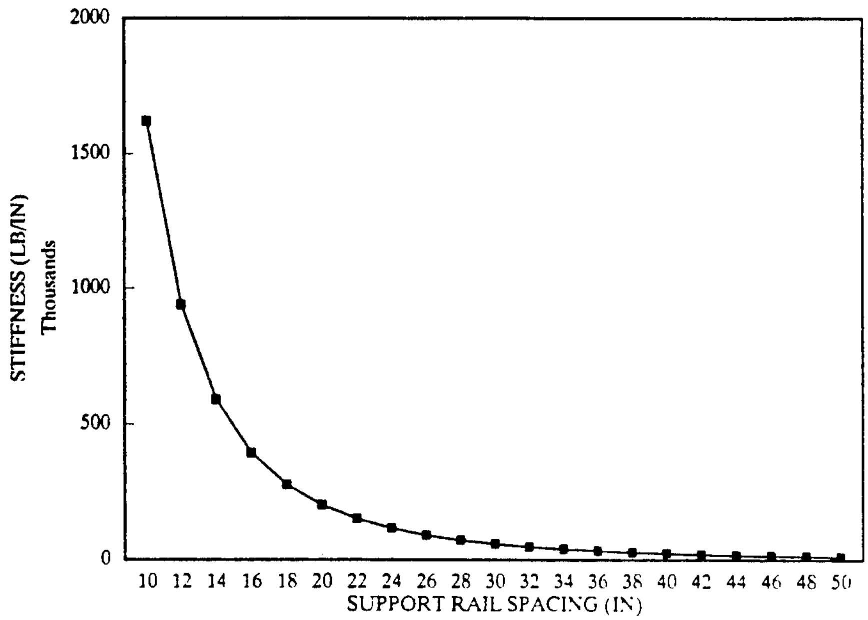
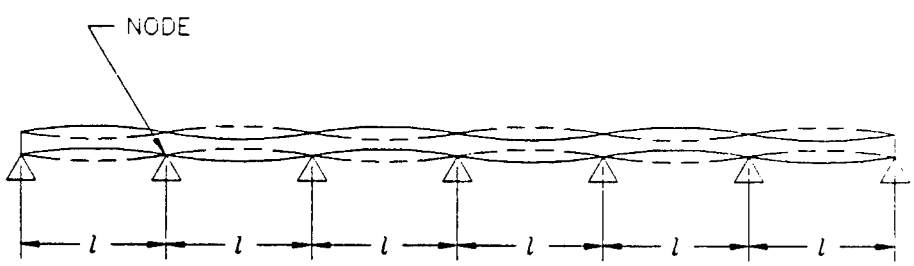


Figure 3. Rail Spring Rate



$$f_n = \frac{\pi}{2l^2}\sqrt{\frac{EIg}{w}}$$

Figure 4. Rail Vibration Mode

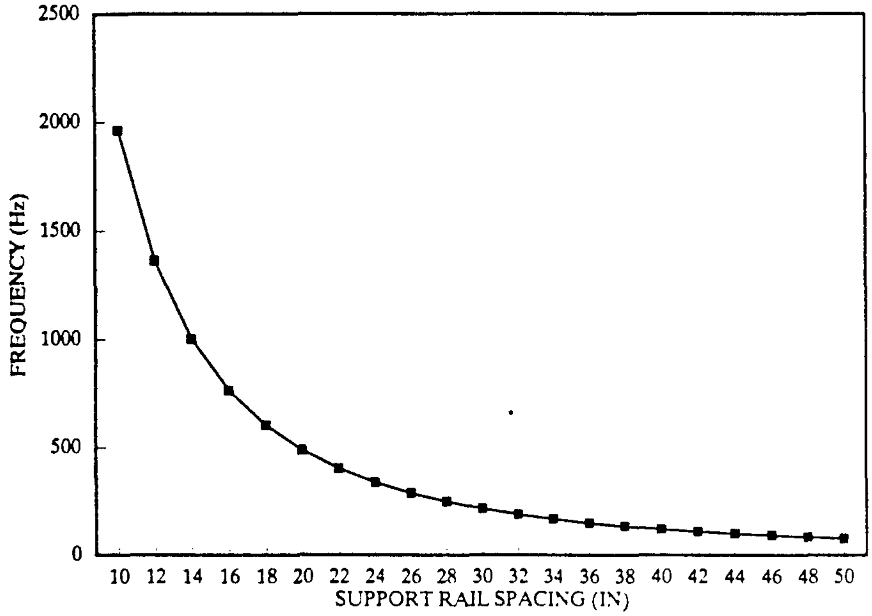
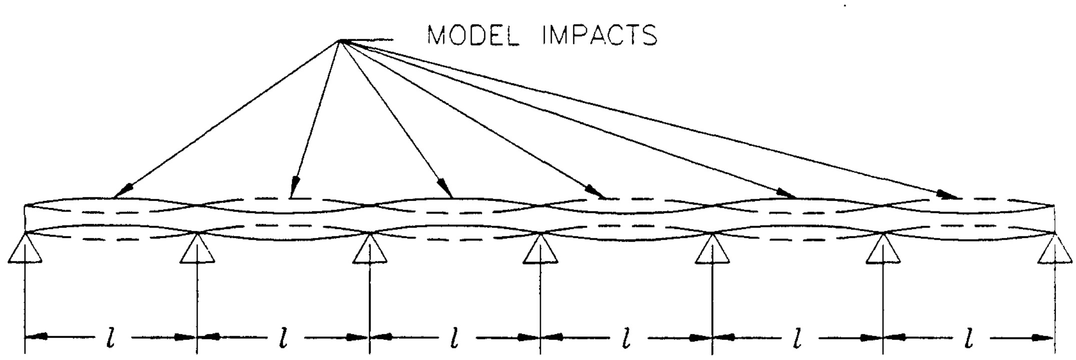


Figure 5. Natural Frequency



$$v = \frac{DIST.}{TIME} = \frac{l}{t/2} \qquad \text{FOR} \quad t = \frac{1}{f} \qquad v = 2lf$$

Figure 6. Excitation Resonance

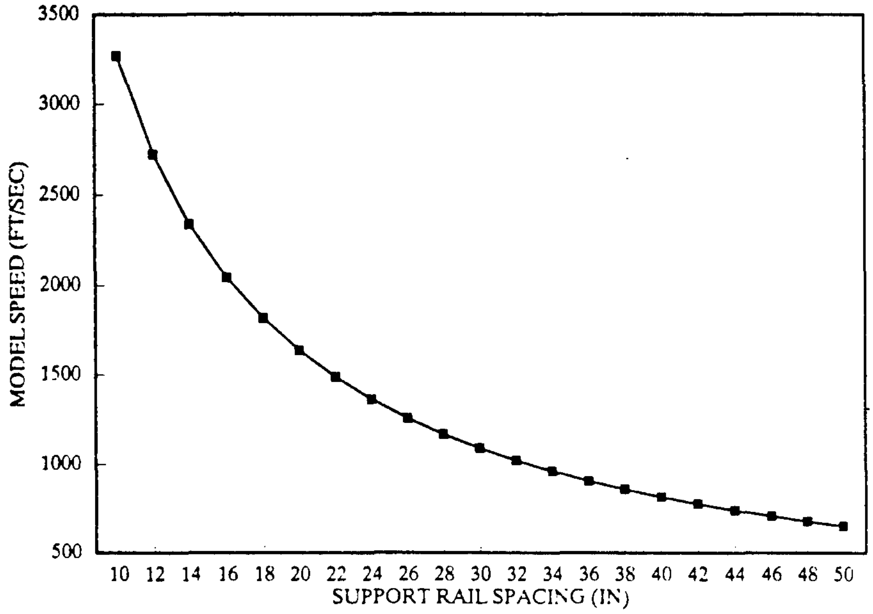


Figure 7. Model Critical Speed

APPENDIX B
RAIL TEST REPORT

INTRODUCTION

This appendix presents the results of the rail tests that were conducted as part of the Track Tapering project. These tests were conducted per the plan presented in QUEST Technical Communication No. 334, "Laboratory Tests for the Adjustable Rail Support System." Two categories of tests were conducted:

- Static stiffness tests to compare the proposed rail mounting system with the existing method.
- Natural frequency measurements to compare the "ringing" in the rail from a projectile impact.

These two series of tests illustrated the behavior of the rail and mounting system under conditions similar to those that might be encountered during track operation. Note that in this report, two different rail sizes are compared: 2.5- and 3.3-inch rails. The 2.5-inch rails refer to the existing rails in the track, which are sized for a 2.5-inch projectile. They are actually 2.25 inches high by 0.75 inch wide. The 3.3-inch rails are sized for a 3.3-inch projectile, and they are actually 1.85 inches high by 1.0 inch wide. These sizes were tested because at the time it was not clear whether the program would be coordinated with the track upgrade to accommodate 3.3-inch projectiles. In the end, the tapering project was coordinated with the track upgrade. However, the final rail size for "3.3" was 1.85 inches high by 0.75 inch wide. The data presented here can be scaled by the area properties to predict the performance for the final rail size.

RAIL STIFFNESS TESTS

The first test was used to establish a stiffness baseline for the existing rail-mounting method. An existing rail was installed in a track support tube at QUEST. The rail was bolted to the support tube on 12-inch centers. Shims were used to space the rail away from the support tube wall in order to simulate a track taper condition. Forces were applied to the mid-span of the rail, and the deflection of the rail face with respect to the support tube wall was measured. Figure B-1 shows the stiffness for bolts on 12- and 36-inch centers. The slopes of these graphs represent the equivalent spring rate of the rail and are shown in the figure.

A bench test was then constructed to test the rail support distances for both the bolting method and for using the new adjuster mechanisms. A second series of tests was run on the 12- and 36-inch support spacing to compare the bench test setup with the tube-mounted tests. As shown in Figure B-2, the results compare quite favorably with the spring rates in the previous figure. These results give good confidence in the bench test setup. Note that some hysteresis is apparent for the loading cycle for the 36-inch support spacing. This was found to be attributable to the seal friction in the hydraulic jack that was used to apply the forces. The hysteresis was eliminated in subsequent tests by adding a load cell to the bench test in order to directly measure the forces applied to the rail.

The complete results of the rail stiffness tests are shown in Figure B-3. The lines on the graph indicate the predicted stiffness based on the modeling in TC-334. Note that approximately 20 percent of stiffness is lost with the actuators in comparison to the bolts. This is because the bolts more closely approximate a fixed end condition that resists moments at the mounting point. The adjusters more closely approximate a simple support that does not resist moments.

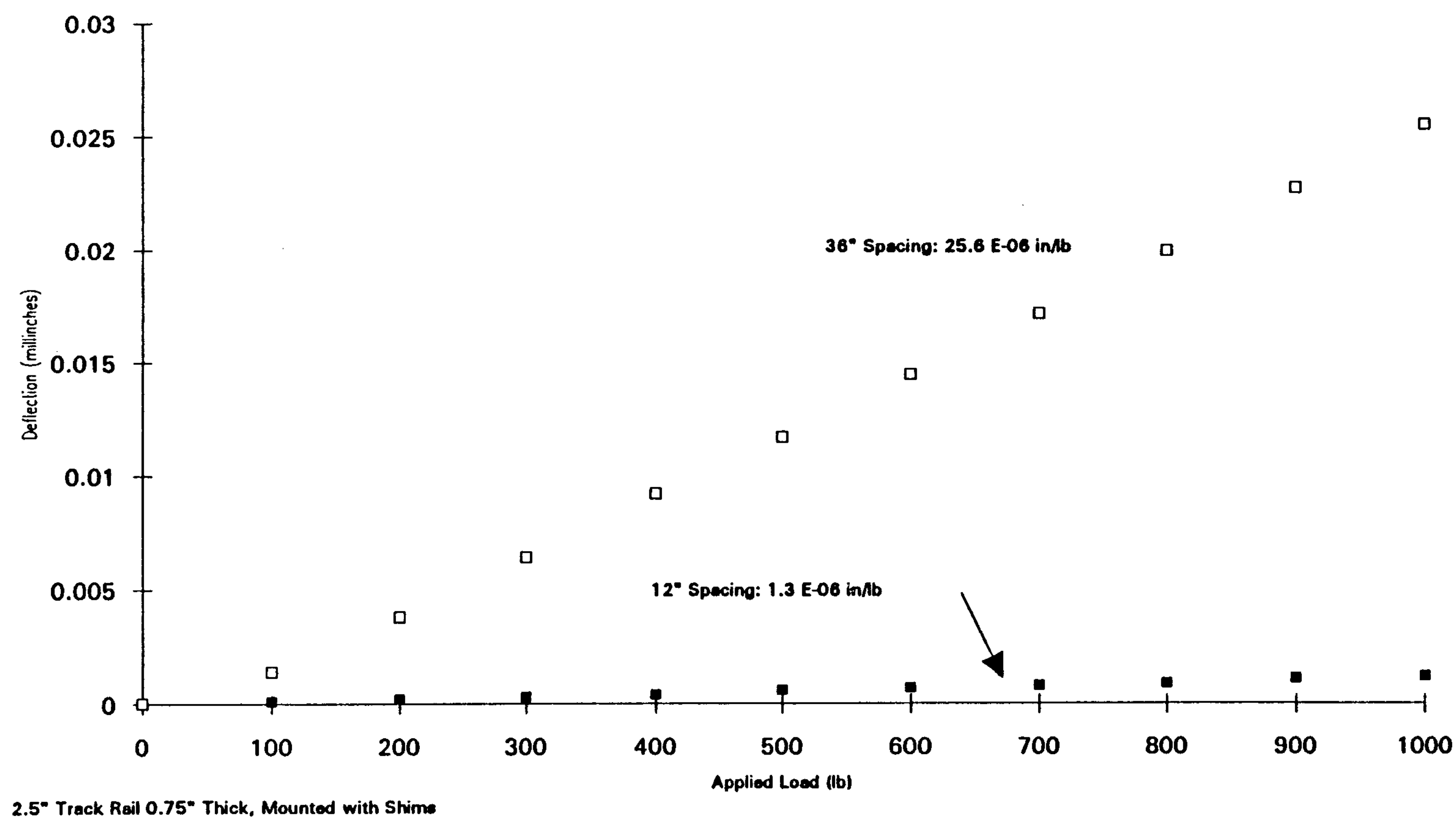


Figure B-1. Baseline Rail Stiffness Results

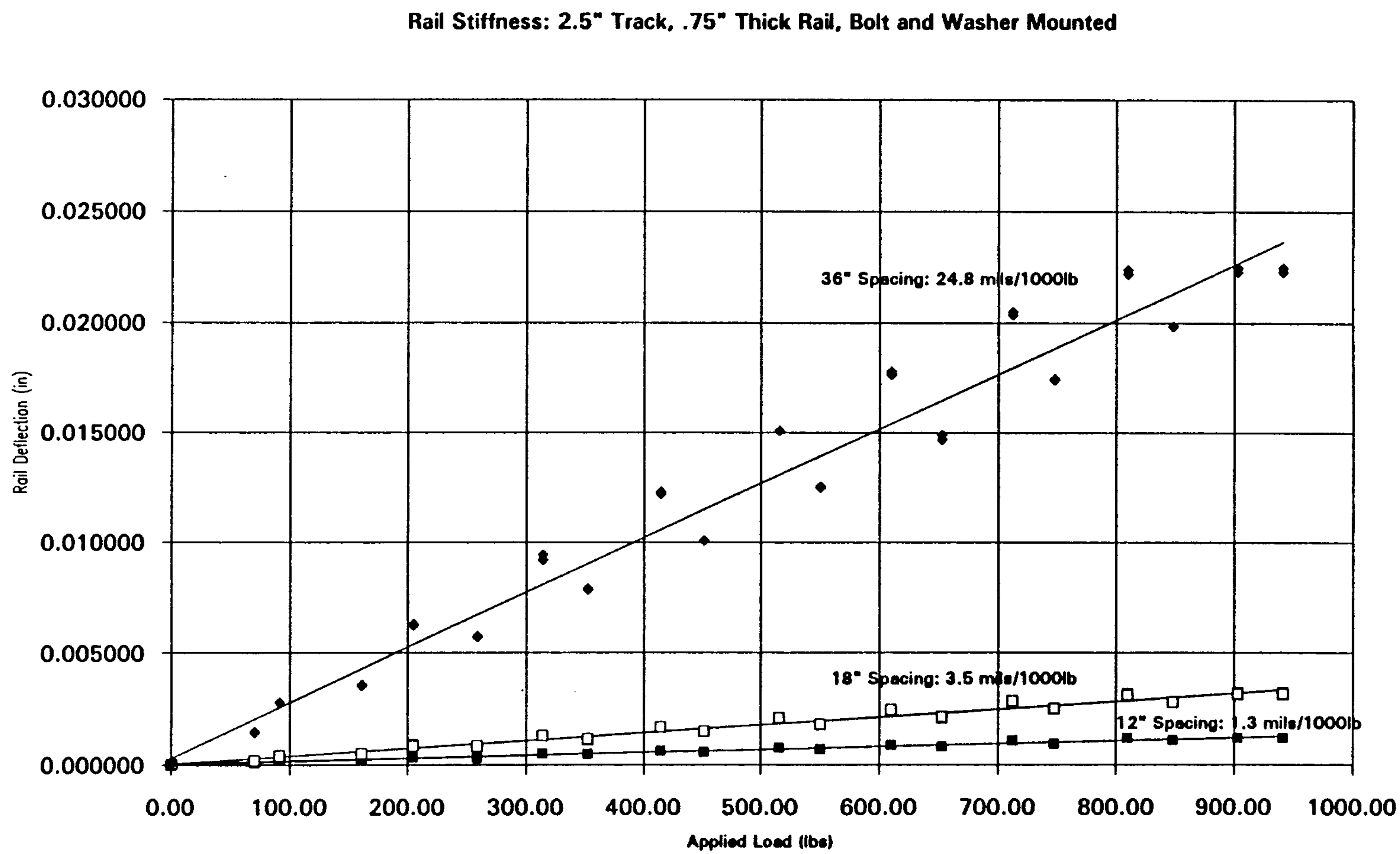
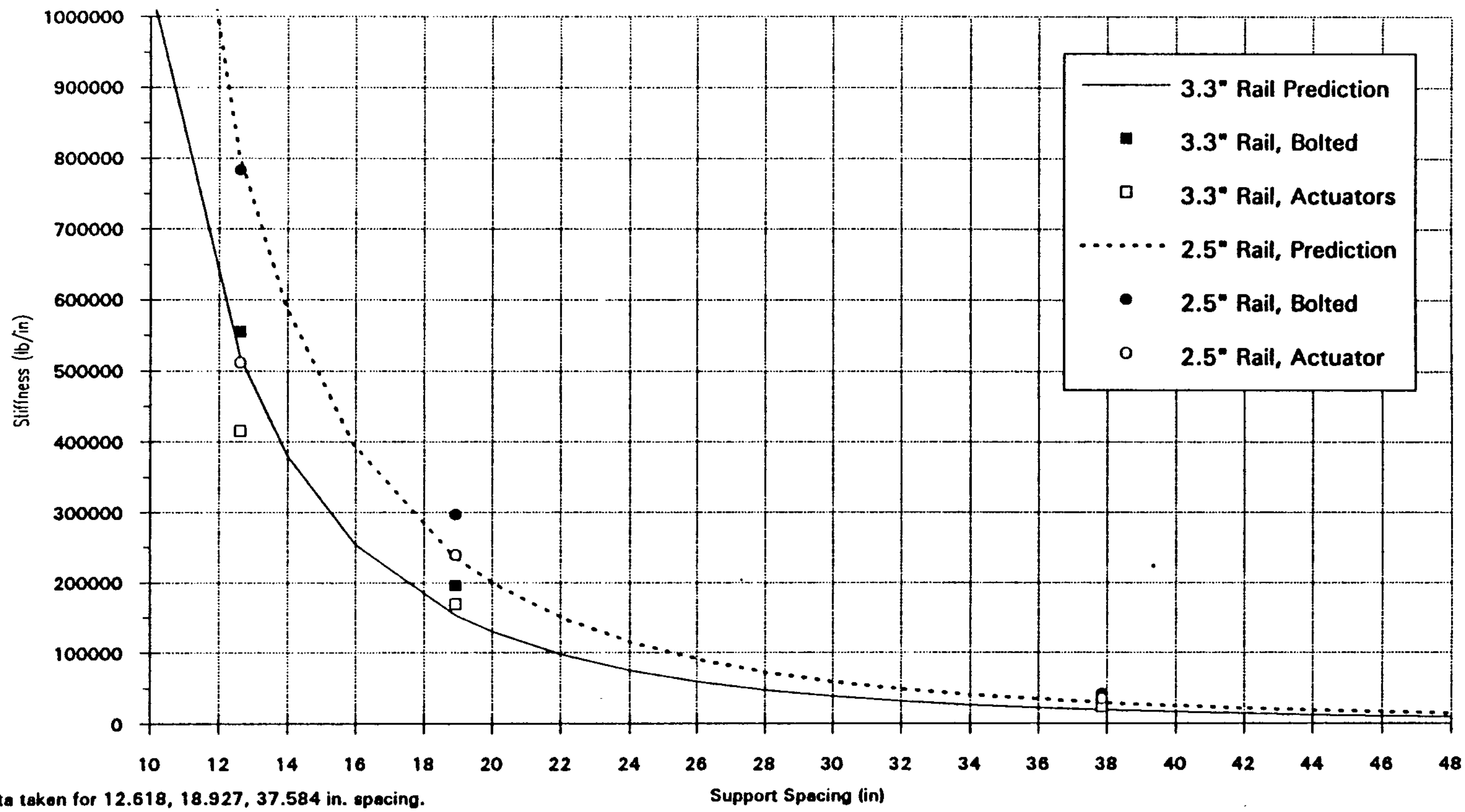


Figure B-2. Bench Test Validation Results



Data taken for 12.618, 18.927, 37.584 in. spacing.

Rail for 3.3" track is 1.0" wide. Rail for 2.5" track is 0.75" wide.

Figure B-3. Rail Stiffness Test Results

NATURAL FREQUENCY TESTS

These tests were conducted to measure the natural frequency of the rail as a function of the distance between bolted mounting points. In these tests, the rails were mounted on the bench fixture from the stiffness tests. An accelerometer was mounted at mid-span between mounting points. Vibrations were excited in the rail by using a soft-blow hammer to simulate a projectile strike. The accelerations of the rail were recorded using a high-speed digital oscilloscope. The data was then transferred to a PC for analysis. A fast Fourier transform was performed to identify the spectrum of vibration response from the rail. The lowest natural frequency was identified from the spectral analysis and graphed in Figure B-4. The line shows predicted response, and the data points are for a 2.5-inch rail. Three support spacings were measured: the existing 12-inch, 18-inch, and 36-inch spacing.

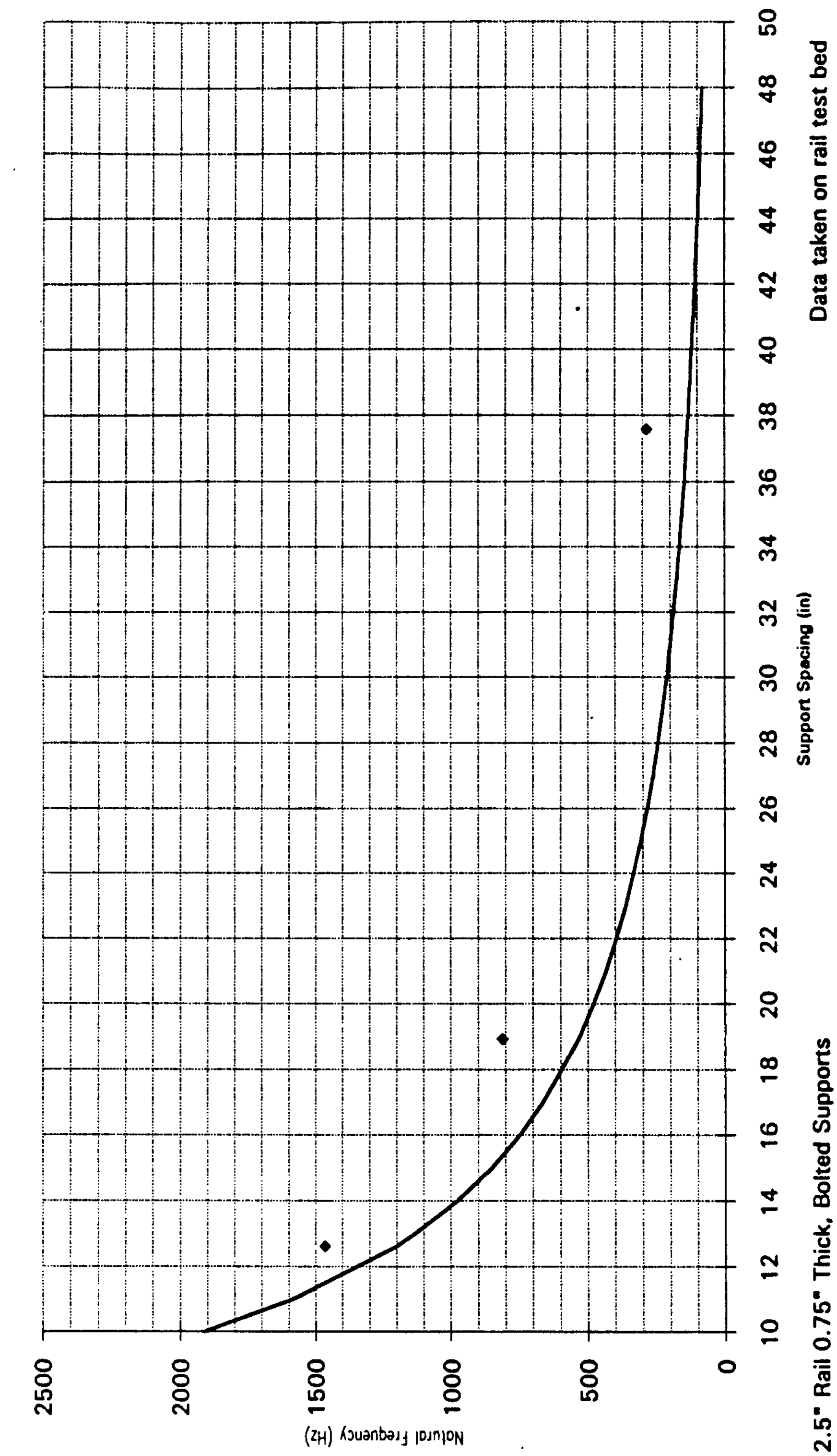


Figure B-4. Natural Frequency Test Results

APPENDIX C
RAIL POSITION GAGE CALIBRATION

INTRODUCTION

This appendix describes the details of the calibration of the rail position gage. It is not recommended that in-depth calibration be performed by the customer. Instead, it recommended that the gage and calibration fixture be returned to QUEST for calibration and service.

The first section of this appendix describes a general principle that is used to compensate for the 10-degree angle between the line of action for the diameter measurement and the line of action for the rail radius measurements. This principle is encoded in the gage software and is transparent to the user. It is included here for completeness. The second section presents the calibration equations that are embedded in the gage software and used for calculating the intercepts for the sensors. The third section provides a map of how these constants are stored and accessed in the rail position gages.

GEOMETRIC COMPENSATION FOR DIAMETER

The Rail Measurement Tool is constructed with a 10-degree angle between the line of measurement for the tube diameter and the line of measurement for the rail positions. This is necessary because the rails block access to the tube wall on the same line of measurement as the rail faces. As shown in Figure C-1, the measurement tool seats against the left side of the support tube internal diameter. The M3 sensor measures the diameter, M1 and M2 measure the positions of rail #1 and rail #2 with respect to the measurement tool body. If the rails maintain position with respect to one another and with respect to the centerline of the support tube, but the internal diameter of the support tube increases by a small amount (ΔR), the measurement tool shifts, as shown in Figure C-2. This shift is because the tool is always referenced on the left side of the figure. Comparing Figure C-1 and Figure C-2, it is clear that sensor M3 changes by the amount of change in the diameter. However, the change in the rail position sensors M1 and M2 is more complicated.

A close-up of the reference contact point is shown in Figure C-3. Both the original and shifted contact points are shown. The distance between these two points, O, is a horizontal shift of the measurement tool and it can be approximated by:

$$O \cong \frac{\Delta R}{\cos(45° - \phi)} \tag{1}$$

Where ϕ is the angle between the lines of action for the measurements. For this measurement tool, ϕ is 10 degrees. Given that the entire tool shifts by amount O, the change in measurement at the rail is shown in Figure C-4. The contact point for M2 shifts horizontally by the same amount O as calculated in Equation 1. The change in sensor M2 after the shift is given by:

$$\Delta M2 = O*\cos(45°) = \frac{M3*\cos(45°)}{2*\cos(35°)} \tag{2}$$

This equation yields the correction factor for this gage geometry. As stated in Figure 11 in the main body of this report:

$$G_c = M3*0.4316 \tag{3}$$

Note that this expression for G_C is about 15 percent different than the simpler case when the lines of action for the two types of measurements coincide.

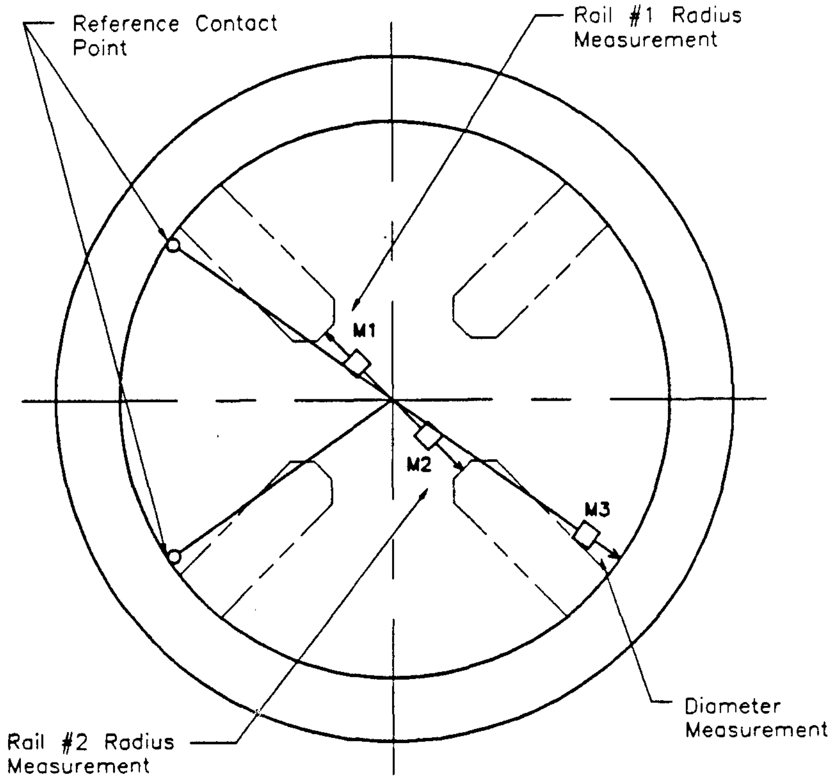


Figure C-1. Nominal Measurement Tool Position

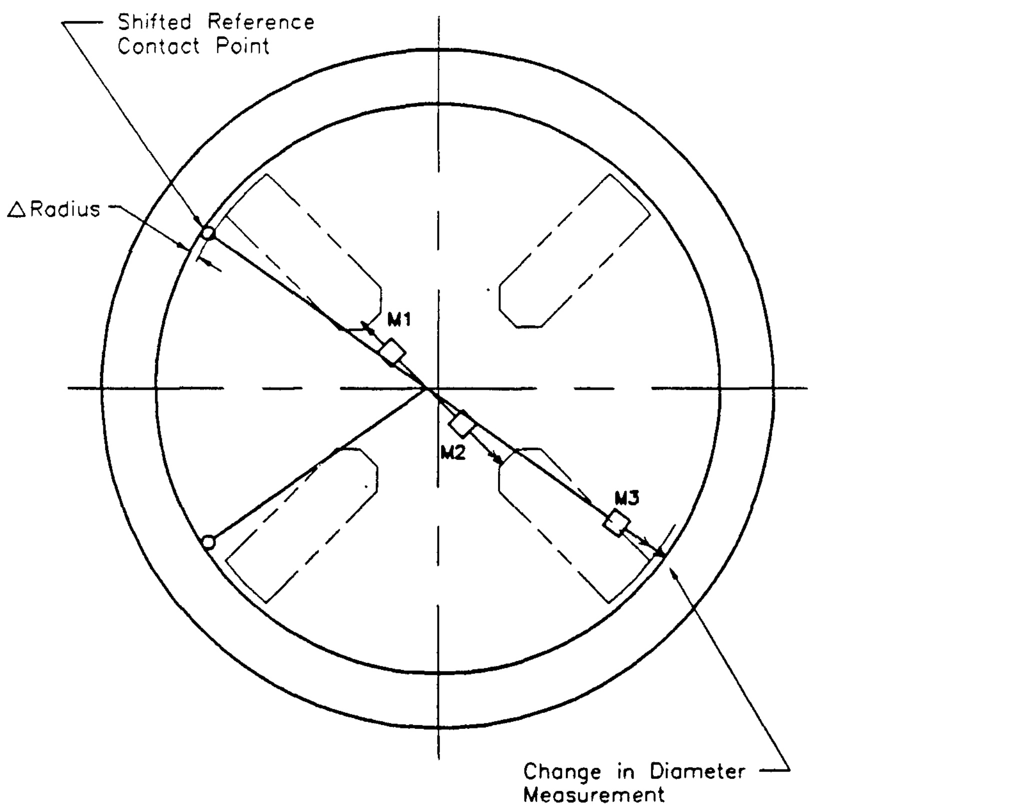


Figure C-2. Tool Shift Due to Increase in Internal Diameter of Support Tube

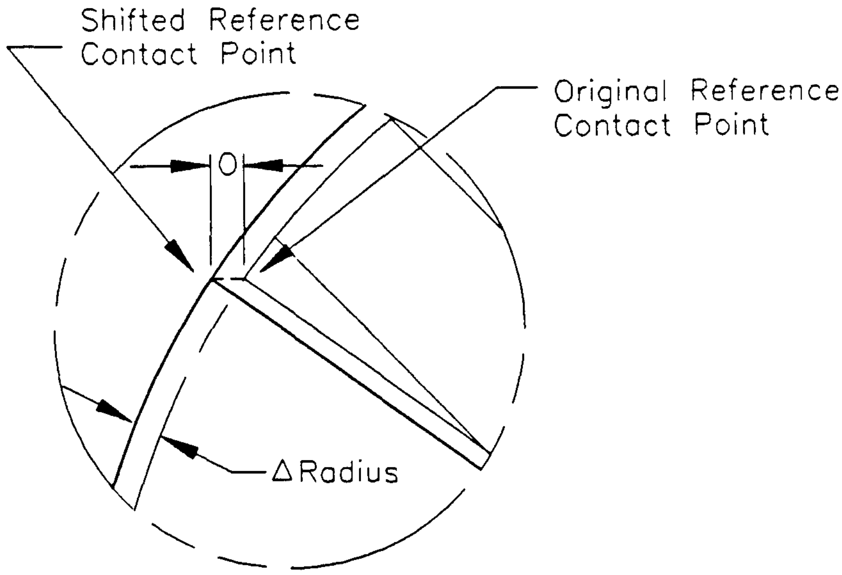


Figure C-3. Reference Contact Point

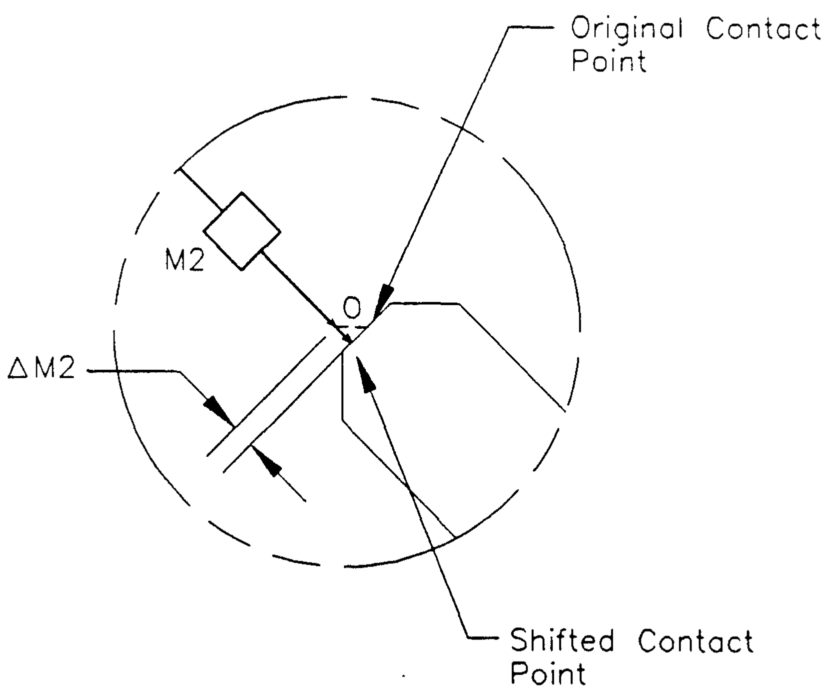


Figure C-4. Rail Measurement Change Due to Tool Shift

RAIL POSITION GAGE CALIBRATION EQUATIONS

This section describes the equations that are used during the automatic calibration sequence. The calibration of the rail position gage requires determining two parameters for a straight line that describes each sensor:

$$Mi = G_i * LVDT_i + O_i \tag{4}$$

where G_i is the gain in volts of sensor output per inch of sensor displacement. This parameter reflects the small variations in the sensitivity of the sensors. $LVDT_i$ is the voltage as read at the input terminals to the embedded computer. This voltage value includes all of the signal conditioning electronics. O_i is the intercept, or the offset to be subtracted from the computed displacement in order for the measurement to be correct for the calibration fixture. This parameter reflects the small errors in the locations of the sensors relative to the reference surfaces of the rail measurement tool.

The slope for each sensor is measured on a bench-top test. A micrometer is used to displace the sensors by known amounts and the resulting voltage output of the sensor is recorded. These values are then stored in the measurement tool controllers according to the description in the next section. By convention, the slopes are stored as positive numbers.

The intercept for each sensor is measured using the calibration fixture. The known dimensions of this fixture are used to calculate the correct offsets for each sensor.

The diameter (M3) sensor must be calibrated first because it couples into the other measurements through the G_c factor. Referring to the equation for the support tube diameter from Figure 11:

$$D_t = M3 + 7.000 = \frac{LVDT_3}{-G_3} + O_3 + 7 \tag{5}$$

Note that the negative sign is introduced because G_3 is actually negative even though it is stored in the tool controller as a positive number. For a known diameter *X1* from QUEST drawing 66572 (see Appendix D):

$$O_3 = X1 + \frac{LVDT_3}{G_3} - 7 \tag{6}$$

This yields the offset for the M3 sensor. To find the offset the M2 sensor, the equation for the radius of rail #2 is used from Figure 11:

$$R_2 = M_2 - G_c = \frac{LVDT_2}{-G_2} + O_2 - G_c \tag{7}$$

From a known rail radius *X3* on QUEST drawing 66572:

$$O_2 = X3 + \frac{LVDT_2}{G_2} + 0.4316\left(\frac{LVDT_3}{-G_3} + O_3\right) \tag{8}$$

Similarly, for finding the offset for the M1 sensor with a known *X2* dimension from QUEST drawing 66572:

$$O_1 = X2 + \frac{LVDT_1}{G_1} - 0.4316\left(\frac{LVDT_3}{-G_3} + O_3\right) \tag{9}$$

These calculations are performed in the measurement tool controller software and are transparent to the user. The next section explains how these constants are stored in the tool controller.

MEMORY MAP FOR CALIBRATION CONSTANTS

The calibration constants for the rail position gage are stored in the EEPROM memory of the embedded control computer. The correct constants have been initialized by QUEST for each of the two rail position gages. In effect, the EEPROM memory acts as a personality module for the gage. The reader is strongly cautioned against changing these constants. The description listed below is for reference only.

The calibration constants are accessed through the "diagnostics" menu. This choice will bring up a submenu, and the "options" choice should be selected. Another sub menu will appear, and the "constants" choice should be selected. These functions require the operator to enter a password. The password is:

7734 <RETURN>

That is, use the keypad on the pendant to enter the numbers 7734 and then the RETURN key on the pendant. Using this password will provide access to the constants listed in Table C-1.

Table C-1. Calibration Constants

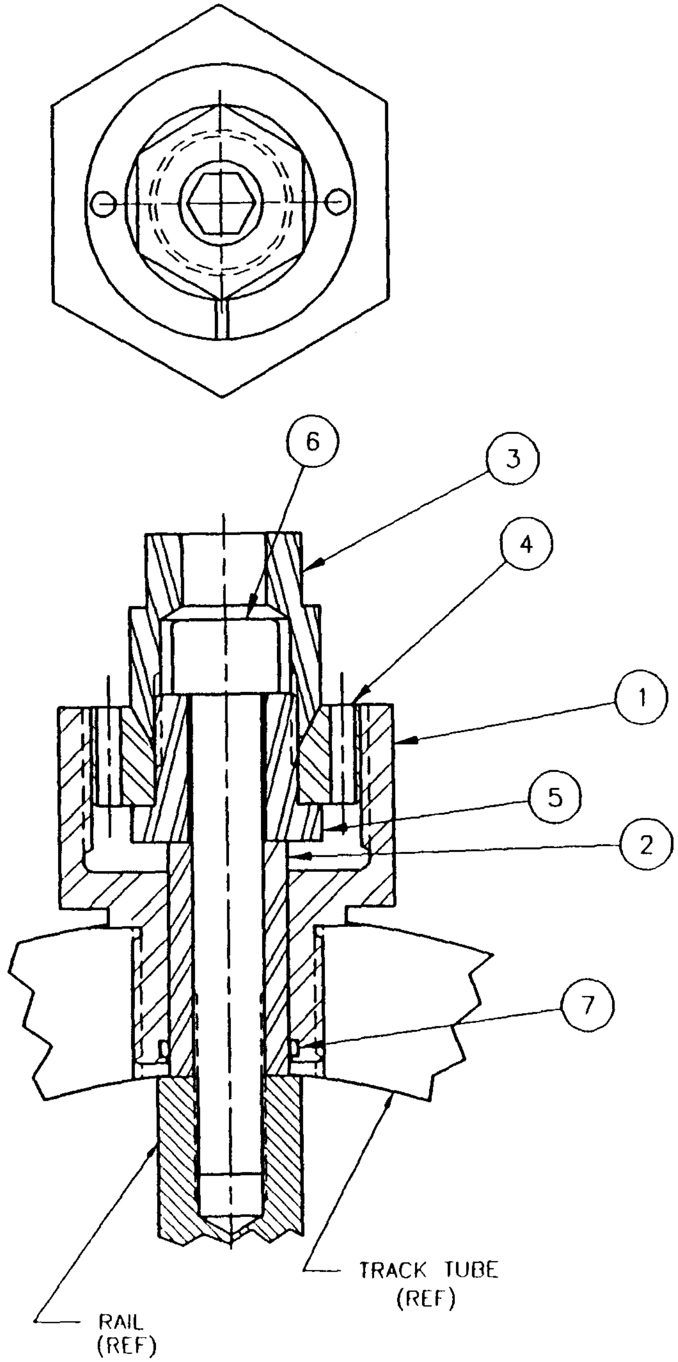
Variable Location	Variable Name	Name	Function	Value for Gage 1	Value for Gage 2
1	X1	Reference Drawing 66572	Diameter of Calibration Fixture	7.00054	7.00054
2	X2	Reference Drawing 66572	Rail #2 Radius of Calibration Fixture	1.65033	1.65033
3	X3	Reference Drawing 66572	Rail #1 Radius of Calibration Fixture	1.65120	1.65120
4	G1	M1	Gain in Volts/Inch	32.7	32.7
5	G2	M2	Gain in Volts/Inch	31.19	34.45
6	G3	M3	Gain in Volts/Inch	33.93	39.91
7	O1	M1	Offset in Inches	1.7	1.7
8	O2	M2	Offset in Inches	1.7	1.7
9	O3	M3	Offset in Inches	0.05	1.7
10	S	Gage Serial Number		1	2

Each constant will be displayed, and a prompt will ask if the constant is to be changed. If not, simply press the return key on the pendant. If so, enter

Y<RETURN>

A new prompt will appear asking for the modified constant value. Note that as soon as the constant is entered it is stored over the old value.

APPENDIX D
ADJUSTER HARDWARE DRAWINGS



PARTS LIST

QTY	ITEM	DESCRIPTION	SPECIFICATION
1	1	BODY #4	64252
1	2	BUSHING	64253
1	3	LOCK NUT	64254
1	4	ADJUSTER #5	64257
1	5	ADAPTER #5	64258
1	6	SOC HD CAP SC, 3/8-24 X 2.5	
1	7	O-RING	2-016

DASH NO.	NEXT ASSY. DWG. NO.	QTY.
-	-	-

USED ON

REV	DATE	DESCRIPTION	BY	CK

REVISIONS

TOLERANCES

(EXCEPT AS NOTED)

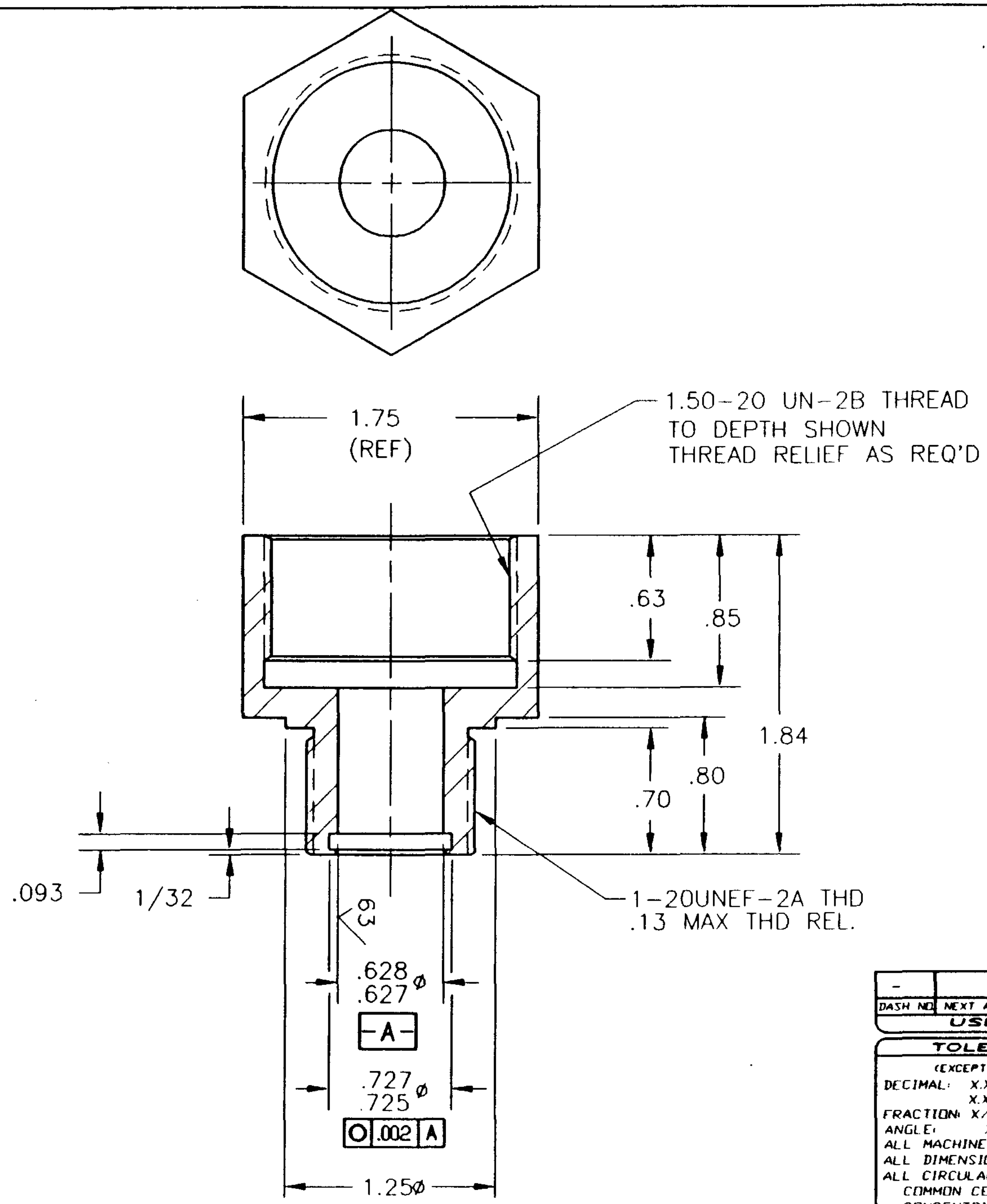
DECIMAL: X.XX = ±.030"
X.XXX = ±.010"
FRACTION: X/X = ±1/16"
ANGLE: X° = ±2°
ALL MACHINED SURFACES: 125√
ALL DIMENSIONS ARE INCHES.
ALL CIRCULAR FEATURES ON COMMON CENTERLINES ARE CONCENTRIC WITHIN .010" Ø.
BREAK ALL SHARP EDGES.

SIGNED
DATE 4-23-91
DRAWN BY MHN
ENGINEER MHM
CHECKED
APPROVED

QUEST INTEGRATED, INC.
21414 68th AVE. SO. KENT WA 98032

TITLE RAIL ADJUSTER #5
TAPER II

SCALE 1:1
DRAWING NUMBER A64251 REV — SH 1



PARTS LIST

QTY	ITEM	DESCRIPTION	SPECIFICATION
1	(1)	HEX BAR, 1-3/4	STEEL, 1018 CF

NOTE:
1. BLACK OXIDE PER MIL-C-13-924 CLASS I.

USED ON

DASH NO	NEXT ASSY. DVG NO	QTY.
-	64251	-

REVISIONS

REV	DATE	DESCRIPTION	BY	CK
B	1-27-92	.13 THD REL WAS MIN.	DR	
A	9-23-91	.628/.627 WAS .626/.625	MHM	

TOLERANCES
(EXCEPT AS NOTED)
DECIMAL: X.XX = ±.030"
X.XXX = ±.010"
FRACTION: X/X = ±1/16"
ANGLE: X° = ±2°
ALL MACHINED SURFACES: 125
ALL DIMENSIONS ARE INCHES.
ALL CIRCULAR FEATURES ON COMMON CENTERLINES ARE CONCENTRIC WITHIN .010" ø
BREAK ALL SHARP EDGES.

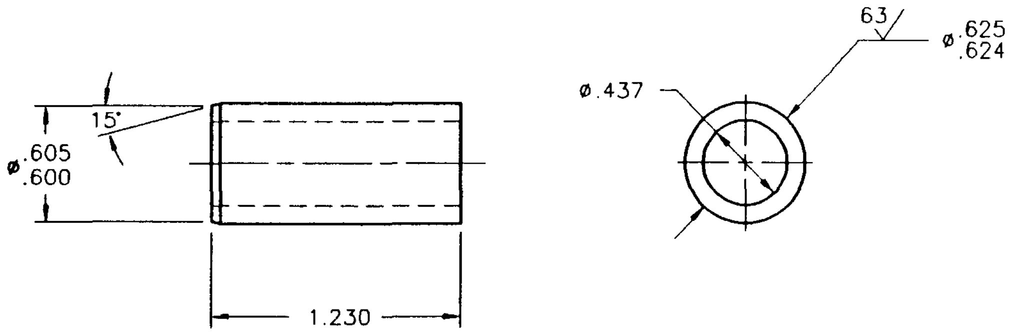
SIGNED	
DATE	4-23-91
DRAWN BY	MHM
ENGINEER	MARVIN
CHECKED	MHM
APPROVED	

QUEST INTEGRATED, INC.
21414 68th AVE. SO. KENT WA 98032

TITLE: BODY #4
TAPER II

SCALE 1:1 | DRAWING NUMBER A64252 | REV B | SH 1

PARTS LIST			
QTY	ITEM	DESCRIPTION	SPECIFICATION
1	1	RD BAR, 5/8ø X 1-1/2" LG	302,303 SS, GROUND



DASH NO	NEXT ASSY. DWG. NO.	QTY
-	64251	1

USED ON

REV	DATE	DESCRIPTION	BY	CK
B	1-17-92	1.230 WAS 1.220, MATL WAS 302	DR	
A	9-25-91	.625/.624 WAS .623/.622	MHM	

REVISIONS

TOLERANCES
(EXCEPT AS NOTED)
DECIMAL: X.XX = ±.030"
X.XXX = ±.010"
FRACTION: X/X = ±1/16"
ANGLE: X° = ±2°
ALL MACHINED SURFACES: 125
ALL DIMENSIONS ARE INCHES.
ALL CIRCULAR FEATURES ON COMMON CENTERLINES ARE CONCENTRIC WITHIN .010" ø.
BREAK ALL SHARP EDGES.

SIGNED
DATE 4-24-91
DRAWN BY MHM
ENGINEER MHM
CHECKED MHM
APPROVED

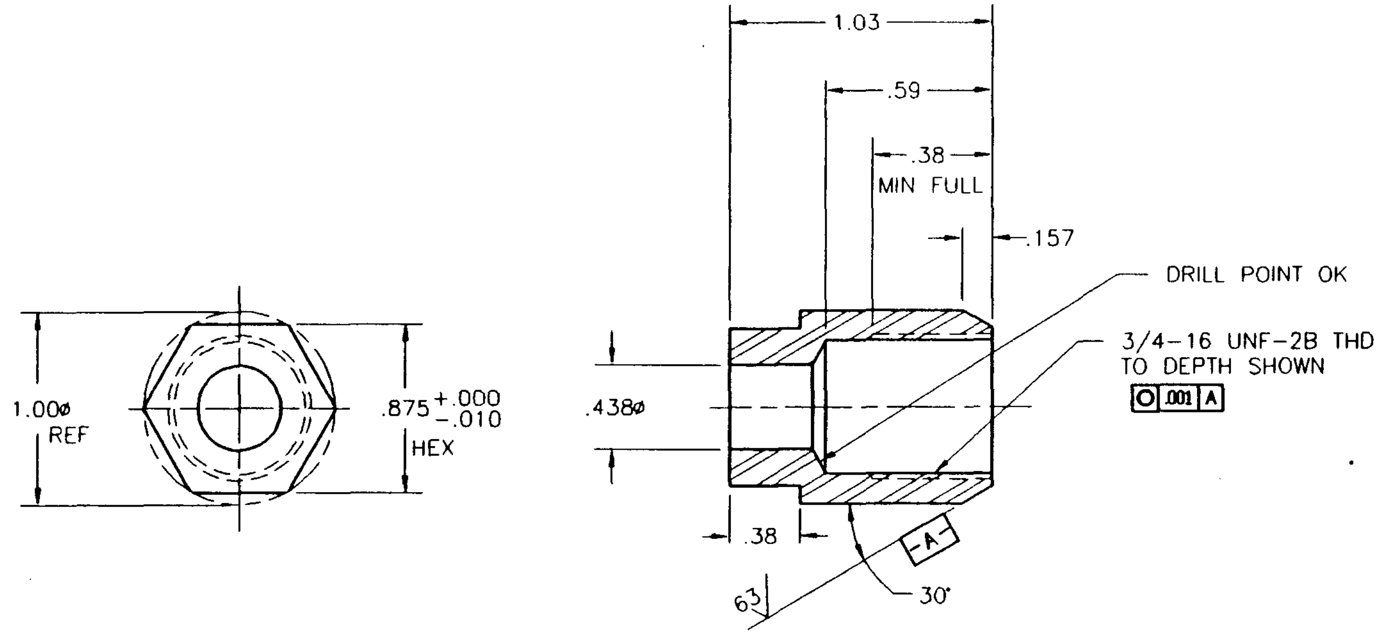
QUEST INTEGRATED, INC.
21414 68th AVE. SO. KENT WA 98032

TITLE **BUSHING**
TAPER II

SCALE 1:1 DRAWING NUMBER A64253 REV B SH 1

PARTS LIST			
QTY	ITEM	DESCRIPTION	SPECIFICATION
1	1	RD BAR 1ø X 1-1/2" LG	12L14 STEEL

NOTE:
1. CARBURIZE TO Rc 50–55, TO .020 DP & BLACK OXIDE FINISH PER MIL. SPEC. C-13924A



-	64251	1
DASH NO	NEXT ASSY DWG NO	QTY

USED ON

REV	DATE	DESCRIPTION	BY	CK
A	2-17-92	HEX WAS .810 FLATS, ADDED .020 DP	DR	

REVISIONS

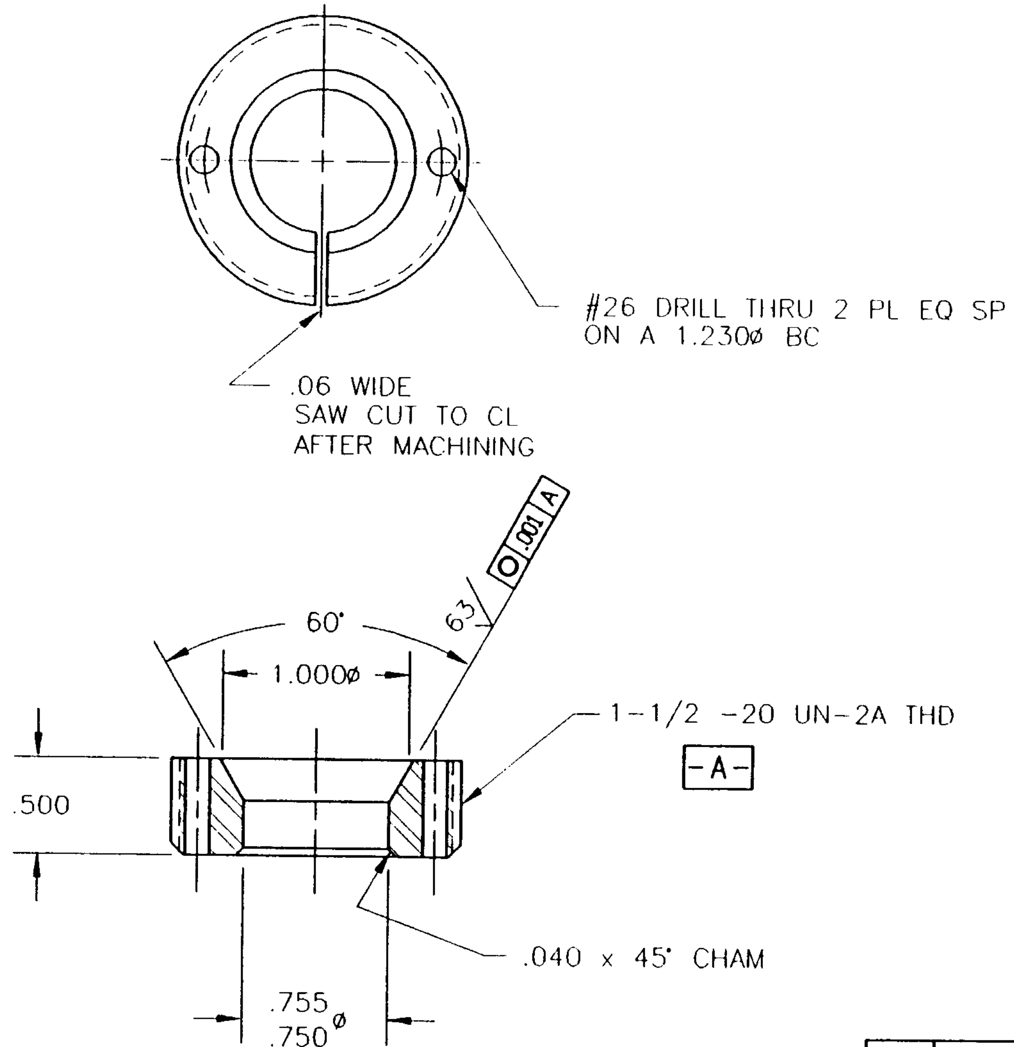
TOLERANCES
(EXCEPT AS NOTED)
DECIMAL: X.XX = ±.030"
X.XXX = ±.010"
FRACTION: X/X = ±1/16"
ANGLE: X° = ±2°
ALL MACHINED SURFACES: 125
ALL DIMENSIONS ARE INCHES.
ALL CIRCULAR FEATURES ON COMMON CENTERLINES ARE CONCENTRIC WITHIN .010" ø.
BREAK ALL SHARP EDGES.

SIGNED
DATE 4-24-91
DRAWN BY MHM
ENGINEER MHM
CHECKED MHM
APPROVED

QUEST INTEGRATED, INC.
21414 68th AVE. SO. KENT WA 98032

TITLE
LOCK NUT
TAPER II

SCALE 1:1 | DRAWING NUMBER A64254 | REV A | SH 1



PARTS LIST

QTY	ITEM	DESCRIPTION	SPECIFICATION
1	(1)	RD BAR, 1-3/4ø X 1/2" LG	660 BRASS

USED ON

DASH NO	NEXT ASSY DWG NO	QTY
-	64251	1

REVISIONS

REV	DATE	DESCRIPTION	BY	CK
A	2-11-91	ADDED .06 WIDE CALLOUT, #26 DR WAS #29	DR	

TOLERANCES

(EXCEPT AS NOTED)
DECIMAL X.XX = ±.030"
X.XXX = ±.010"
FRACTION X/X = ±1/16"
ANGLE X° = ±2°
ALL MACHINED SURFACES 125
ALL DIMENSIONS ARE INCHES
ALL CIRCULAR FEATURES ON COMMON CENTERLINES ARE CONCENTRIC WITHIN .010" ø
BREAK ALL SHARP EDGES.

SIGNED

DATE 4-24-91
DRAWN BY MHM
ENGINEER MARVIN
CHECKED MHM
APPROVED

QUEST INTEGRATED, INC.
21414 68th AVE. SO KENT WA 98032

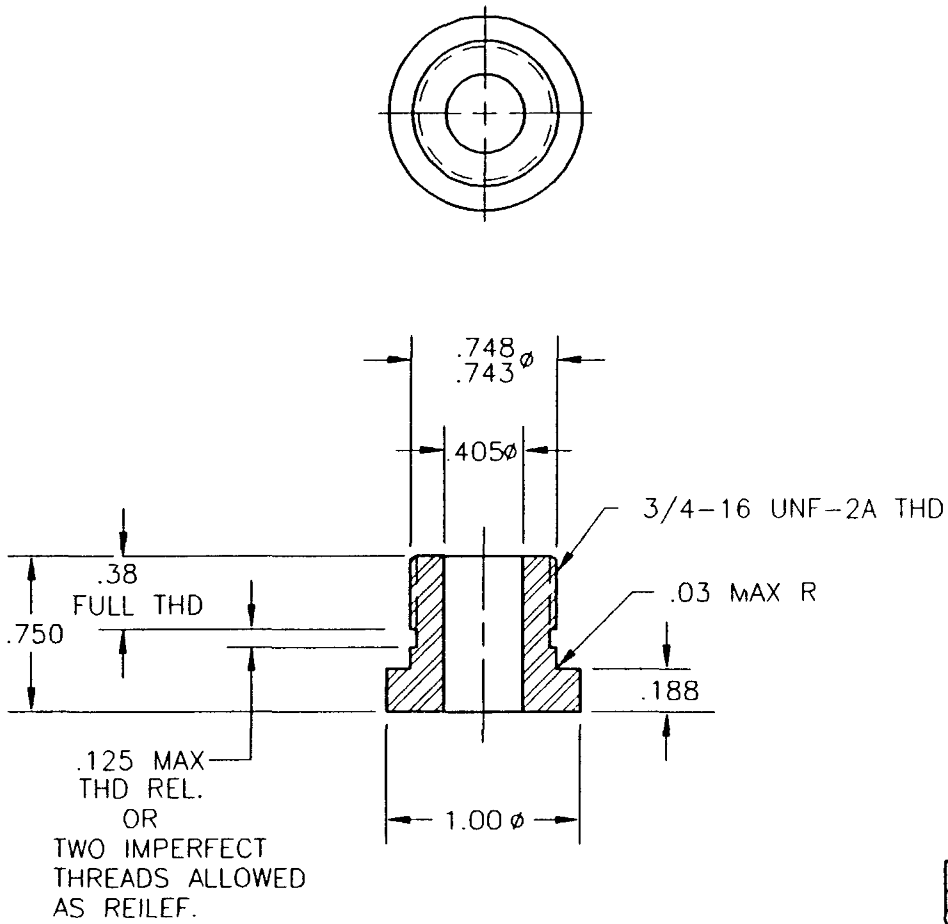
TITLE ADJUSTER #5
TAPER II

SCALE 1:1 DRAWING NUMBER A64257 REV A SH 1

PARTS LIST			
QTY	ITEM	DESCRIPTION	SPECIFICATION
1	1	1ø ROUND BAR	12L14 CF

NOTE:

1. BLACK OXIDE PER MIL-CB-924 CLASS I.



DASH NO	NEXT ASSY. DWG NO.	QTY.
-	64251	1

USED ON

REV	DATE	DESCRIPTION	BY	CK
A	2-21-92	MATL WAS MILD STL, ADDED THD REL	DR	

REVISIONS

TOLERANCES

(EXCEPT AS NOTED)
DECIMAL: X.XX = ± .030"
X.XXX = ± .010"
FRACTION: X/X = ± 1/16"
ANGLE: X° = ± 2°
ALL MACHINED SURFACES: 125
ALL DIMENSIONS ARE INCHES.
ALL CIRCULAR FEATURES ON COMMON CENTERLINES ARE CONCENTRIC WITHIN .010" ø
BREAK ALL SHARP EDGES.

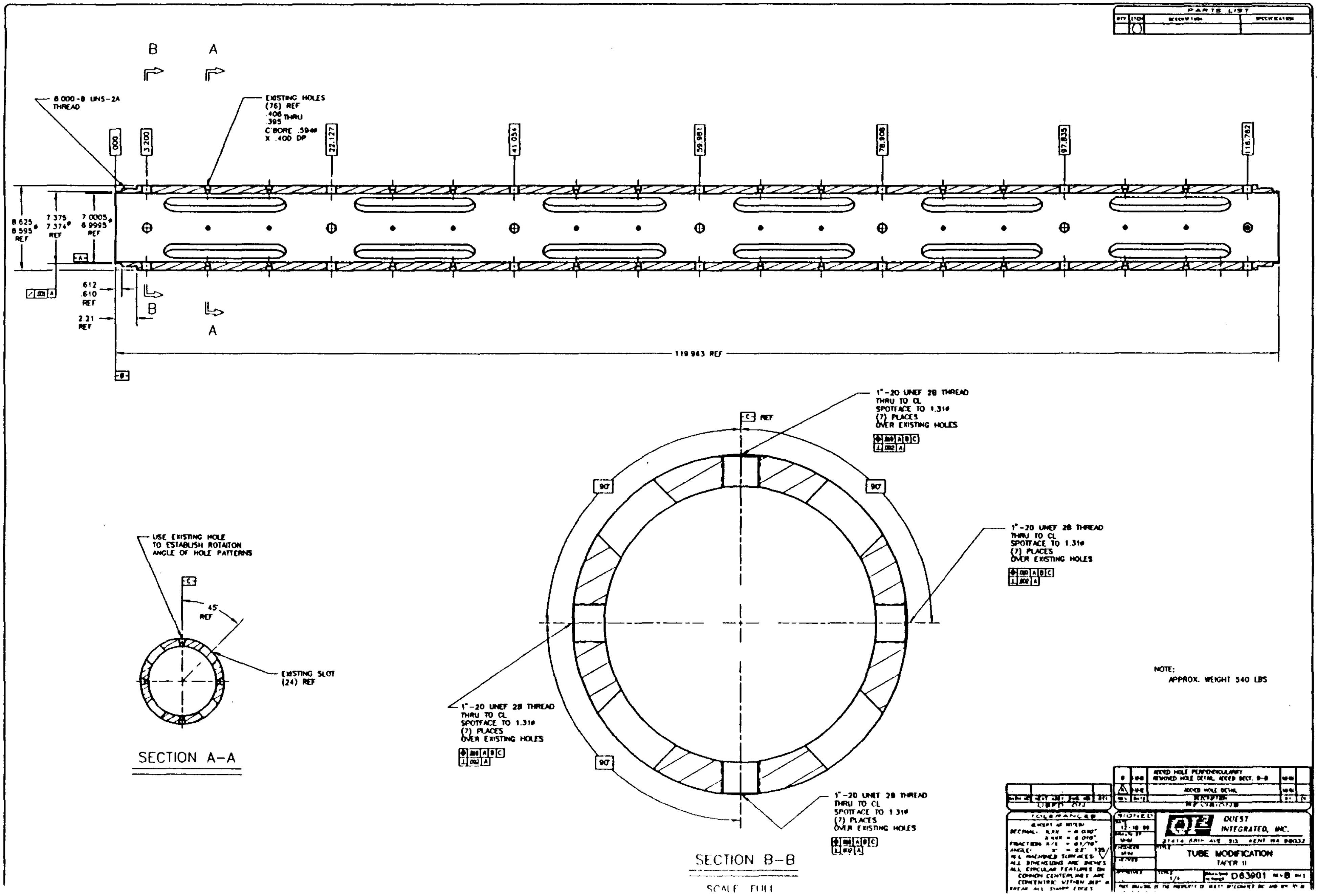
SIGNED

DATE	4-24-91
DRAWN BY	MHM
ENGINEER	MARVIN
CHECKED	MHM
APPROVED	

QUEST INTEGRATED, INC.
21414 68th AVE. SO. KENT WA 98032

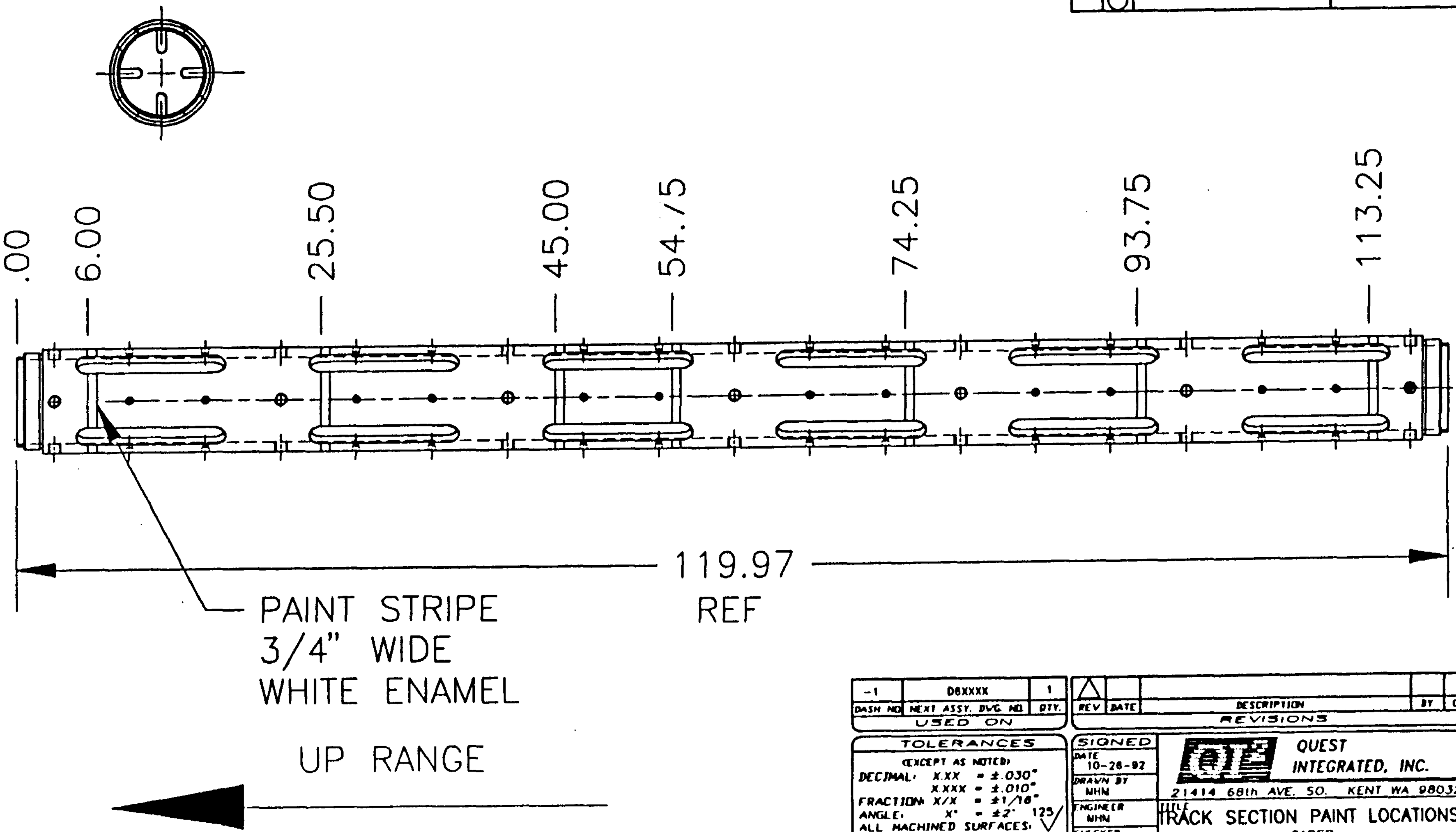
TITLE: ADAPTER #5
TAPER II

SCALE 1:1 | DRAWING NUMBER A64258 | REV A | SH 1



8.000-8 UNS-2A THREAD
EXISTING HOLES (76) REF .406 .395 THRU C'BORE .594⌀ X .400 DP
.000
3.200
22.127
41.054
59.981
78.908
97.835
116.762
8.625 8.595⌀ REF
7.375 7.374⌀ REF
7.0005 6.9995⌀ REF
.612 .610 REF
2.21 REF
119.963 REF
USE EXISTING HOLE TO ESTABLISH ROTATION ANGLE OF HOLE PATTERNS
45° REF
EXISTING SLOT (24) REF
SECTION A-A
1"-20 UNEF 2B THREAD THRU TO CL SPOTFACE TO 1.31⌀ (7) PLACES OVER EXISTING HOLES
90°
SECTION B-B
SCALE FULL
NOTE: APPROX. WEIGHT 540 LBS
ADDED HOLE PERPENDICULARITY REMOVED HOLE DETAIL, ADDED SECT. B-B
ADDED HOLE DETAIL
QUEST INTEGRATED, INC.
TUBE MODIFICATION
D63901

QTY	ITEM	DESCRIPTION	SPECIFICATION
		PARTS LIST	



DASH NO.	NEXT ASSY. DWG. NO.	QTY.
-1	D8XXXX	1

USED ON

REV	DATE	DESCRIPTION	BY	CK

REVISIONS

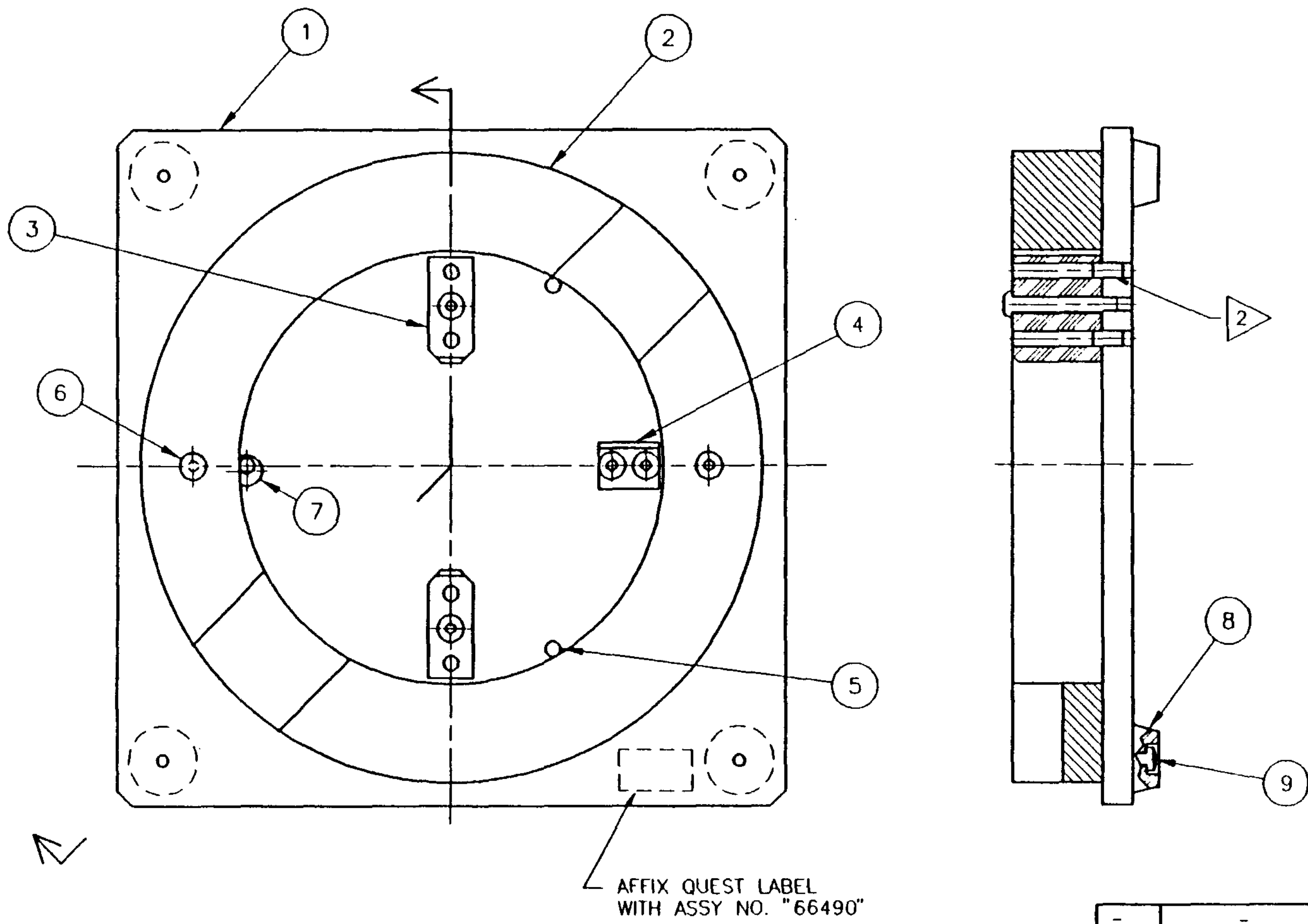
TOLERANCES
(EXCEPT AS NOTED)
DECIMAL: X.XX = ±.030"
X.XXX = ±.010"
FRACTION: X/X = ±1/16"
ANGLE: X° = ±2°
ALL MACHINED SURFACES: 125√
ALL DIMENSIONS ARE INCHES.
ALL CIRCULAR FEATURES ON COMMON CENTERLINES ARE CONCENTRIC WITHIN .010" ⌀.
BREAK ALL SHARP EDGES.

SIGNED
DATE 10-28-92
DRAWN BY NHN
ENGINEER NHN
CHECKED
APPROVED

QI² QUEST INTEGRATED, INC.
21414 68th AVE. SO. KENT WA 98032

TITLE
TRACK SECTION PAINT LOCATIONS
TAPER

SCALE 1/8
DRAWING NUMBER B 65609 REV — SH 1



PARTS LIST

QTY	ITEM	DESCRIPTION	SPECIFICATION
1	1	BASE PLATE	66491
1	2	CALIB RING	66492
2	3	RAIL BLOCK	66493
1	4	PRELOAD BLOCK	66494
7	5	1/4 DIA X 1/2 DOWEL	ST STEEL
8	6	1/4 DIA x 1-3/4 BHCS	BLACK OXIDE
1	7	ECCENTRIC LINER	CARR-LANE CL-4-SLPE
4	8	RUBBER FEET	BUDWIG SF10
4	9	#8-32 x 1/2 PHMS	BLACK OXIDE
1	10	INSPECTION REQUIREMENTS	66572

NOTES:

1. SEE DWG #66572 FOR ASSEMBLY DIMENSIONS AND INSPECTION REQUIREMENTS.

2. DOWEL HEADS IN THIS POSITION MAY BE RELIEVED TO A DIAMOND SHAPE

USED ON

DASH NO	NEXT ASSY DWG NO	QTY.
-	-	-

REVISIONS

REV	DATE	DESCRIPTION	BY	CK
A	4-22-93	FAB	JH	

TOLERANCES

(EXCEPT AS NOTED)
DECIMAL: X.XX = ± .030"
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ANGLE: X° = ±2°
ALL MACHINED SURFACES: 125
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BREAK ALL SHARP EDGES.

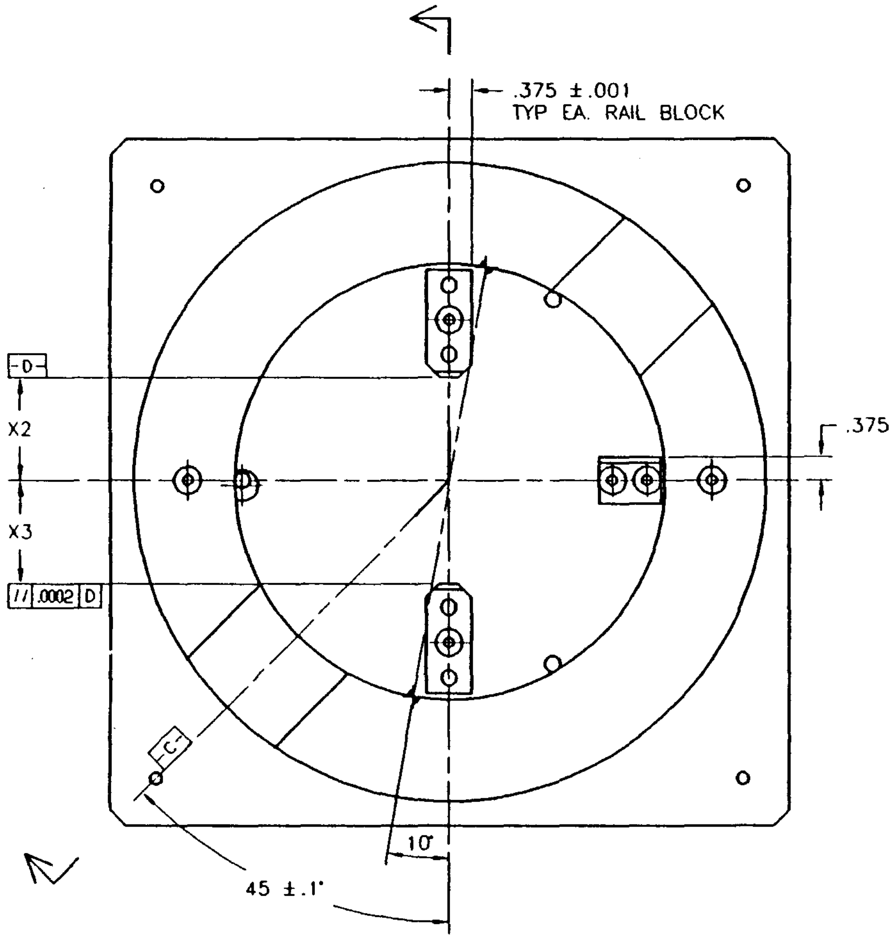
SIGNED	
DATE	3-31-93
DRAWN BY	JH
ENGINEER	JH
CHECKED	
APPROVED	

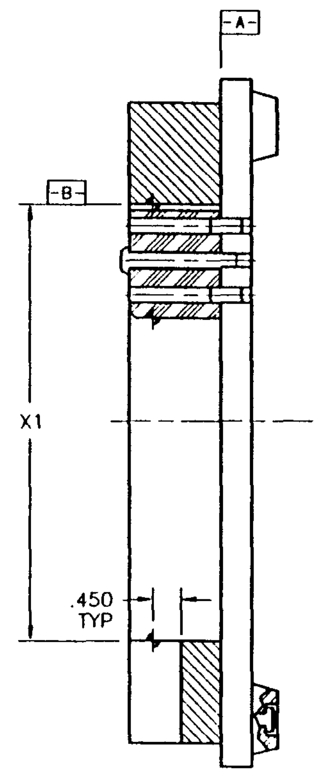
QUEST INTEGRATED, INC.
21414 68th AVE. SO. KENT WA 98032

TITLE: MASTER GAGE ASSY
TAPER - II

SCALE 1:2 | DRAWING NUMBER B 66490 | REV A | SH 1

PARTS LIST			
QTY	ITEM	DESCRIPTION	SPECIFICATION
1	1	MASTER GAGE ASSY	66490





DIM	ASSY TOL	ACTUAL MSMT	ACCURACY
X1	7.000 7.001		0.0002
X2	1.651 1.650		0.0002
X3	1.651 1.650		0.0002

DASH NO	NEXT ASSY. DWG. NO	QTY.
-	66490	1

USED ON

REV	DATE	DESCRIPTION	BY	CK
A	4-22-93	FAB	JH	

REVISIONS

TOLERANCES
(EXCEPT AS NOTED)
DECIMAL: X.XX = ± .030"
X.XXX = ± .010"
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ANGLE: X° = ±2°
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BREAK ALL SHARP EDGES.

SIGNED
DATE 4-23-93
DRAWN BY JH
ENGINEER JH
CHECKED
APPROVED

QUEST INTEGRATED, INC.
21414 68th AVE. SO. KENT WA 98032

TITLE
INSPECTION – MASTER GAGE
TAPER – II

SCALE 1:2
DRAWING NUMBER B 66572 REV A SH 1

/

EDMUNDS GAGES

INSPECTION REPORT

Job No. 214156 Date 6-11-93 Sheet 1 of 1

First Piece — In Process — Final ✓

Customer QUEST INTEGRATED, INC. Purchase Order No. QP 19945

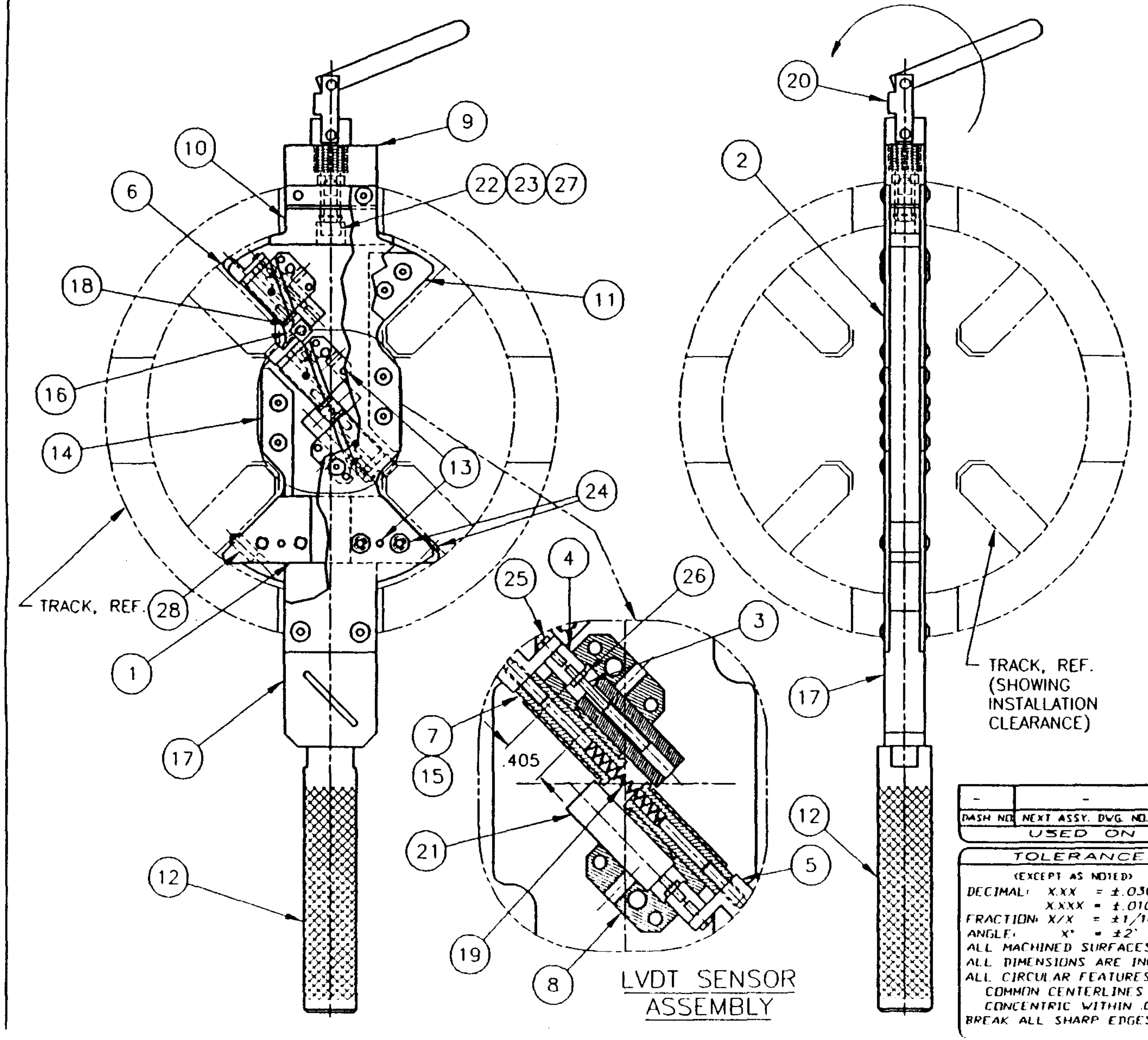
DWG No. B66572 Part Name INSP - MASTER GAGE Material —

Quantity Ordered 1 Quantity Inspected 1

Check	Specification	Tol.	Actual Size	Variation	Basic	Deviation
"X1"	7.000 / 7.001	—	7.00054	—		
"X2"	1.651 / 1.650	—	1.65033	—		
"X3"	1.651 / 1.650	—	1.65120	—		

Inspected by [signature] Disposition —

INSP 4



PARTS LIST			
QTY	ITEM	DESCRIPTION	SPECIFICATION
1	1	TUBE REF BLOCK	QUEST #63933
2	2	SIDE PLATE	QUEST #64839
3	3	LVDT SHAFT	QUEST #63935
3	4	PLUNGER GUIDE	QUEST #63936
2	5	RAIL CONTACT POINT	QUEST #63937
1	6	TUBE CONTACT POINT	QUEST #63938
3	7	PLUNGER	QUEST #64840
3	8	LVDT HOUSING	QUEST #64841
1	9	CAM MOUNTING BLOCK	QUEST #63941
1	10	TUBE I.D. STOP	QUEST #63942
1	11	SIDE PLATE SPACER	QUEST #63945
1	12	HANDLE	QUEST #64628
8	13	ROLL PIN	1/8ø X 3/4 LG SS
1	14	COVER	QUEST #64920
3	15	SOC HD SET SCREW	#6-32 x 3/8 SS
1	16	SPRING ANCHOR BLOCK	QUEST #63956
1	17	BOTTOM SPACER BAR	QUEST #63960
1	18	SPRING #A11-62	CENTURY
1	19	SPRING #354-C	CENTURY
1	20	CAM HANDLE CARR-LANE	#CL-150-TPC
3	21	LVDT, TRANS-TEK	#0273-0000
1	22	1/4-20 SHCS x 1- 1/2	S STL
1	23	NUT 1/4-20 JAM	S STL
31	24	SOC BUTTON HD SCW	#8-32 x 1/4 SS
3	25	SLOTTED RND HD SCW	#1-72 x 1/4 SS
3	26	NUTS #1-72	S STL
8	27	BELLEVILLE SPRING	# B0500-025-S
1	28	SPRING PLUNGER	CARR LANE CL-43-SSPS-1

DASH NO.	NEXT ASSY. DWG. NO.	QTY.
-	-	-

USED ON

REV	DATE	DESCRIPTION	BY	CK

REVISIONS

TOLERANCES
(EXCEPT AS NOTED)
DECIMAL: X.XX = ±.030"
X.XXX = ±.010"
FRACTION: X/X = ±1/16"
ANGLE: X° = ±2°
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ALL DIMENSIONS ARE INCHES
ALL CIRCULAR FEATURES ON COMMON CENTERLINES ARE CONCENTRIC WITHIN .010" ø
BREAK ALL SHARP EDGES.

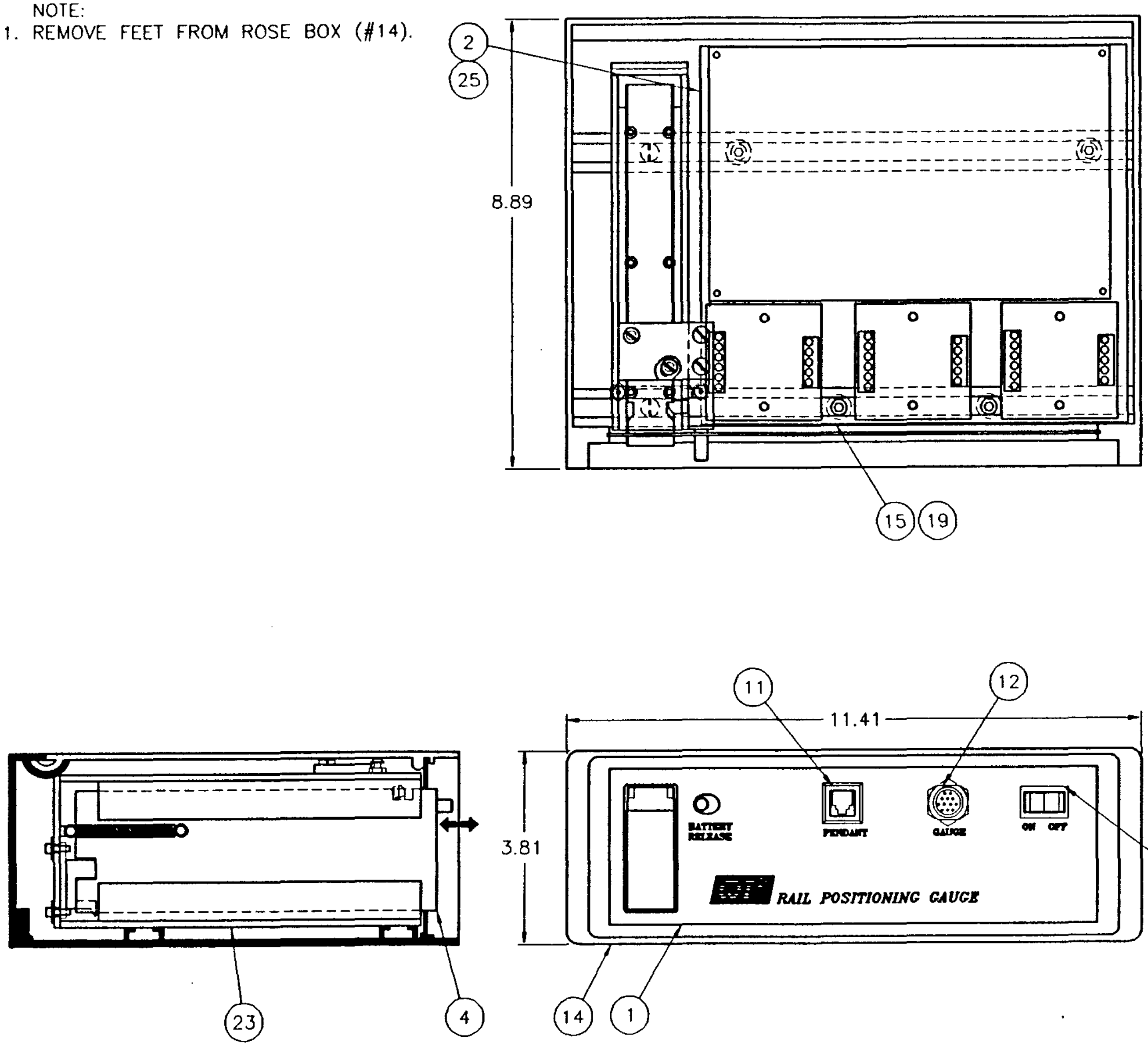
SIGNED
DATE 2/27/92
DRAWN BY LARKIN
ENGINEER MARVIN
CHECKED
APPROVED

QUEST INTEGRATED, INC.
21414 68th AVE. SO. KENT WA 98032

TITLE RAIL GAGE ASSEMBLY-3.3
TAPER II

SCALE 1:2 | DRAWING NUMBER B 64838 | REV — | SH 1

NOTE:
1. REMOVE FEET FROM ROSE BOX (#14).



PARTS LIST

QTY	ITEM	DESCRIPTION	SPECIFICATION
1	1	FRONT PANEL	65487
1	2	ELECTRONICS PLATE	65488
1	4	BATTERY(MICROPWR ELECTRONICS)	MPE-BP88
1	11	RECEPTACLE	HIROSE H9083
1	12	RECEPTACLE	HIROSE HR209-ND
1	13	ROCKER SWITCH	G00395
1	14	ENCLOSURE	ROSE 07400125
4	15	SPACER FOR #10 SCW	3/8 HIGH 1/2# NYLON
4	19	SHCS #10-32 x 1/2	S STL
1	23	BATTERY HOLDER ASSEMBLY	65588
1	24		
1	25	ELECTRONICS BOARD	

REV	DATE	DESCRIPTION	BY	CK
		FIRST ISSUE		

REVISIONS

TOLERANCES
DIMENSIONS ARE FOR REFERENCE ONLY

DASH NO	NEXT ASSY DWG NO	QTY
-1		1

USED ON

MAKE QTY	CHARGE NO	ENGR EXT
DATE REQ'D	QUALITY PLAN NO	EST. HOURS
MACHINIST		ACTUAL HOURS

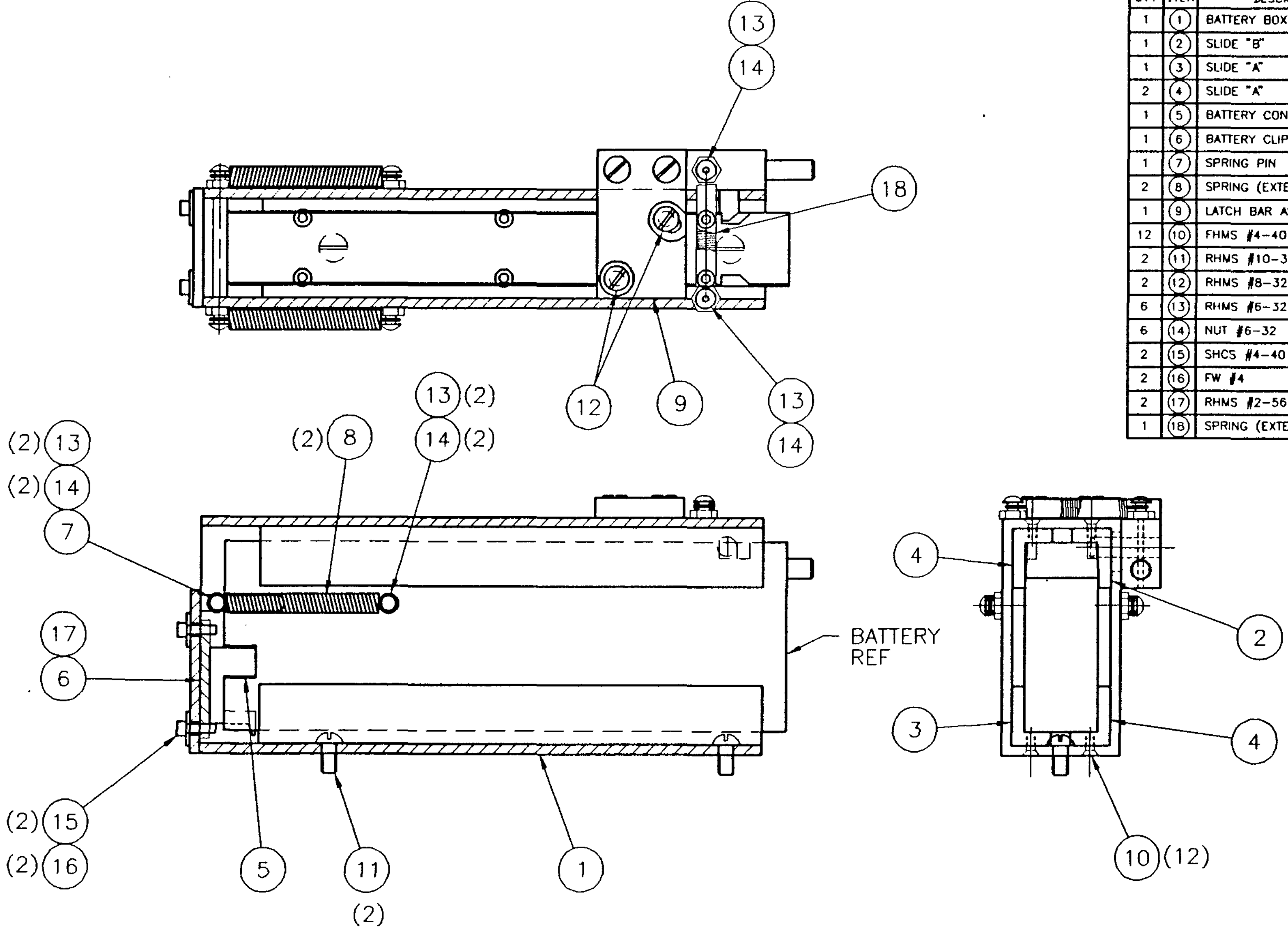
SHOP INSTRUCTIONS

SIGNED
DATE 10/1/92
DRAWN BY D ROOK
ENGINEER M MARVIN
CHECKED
APPROVED

QUEST INTEGRATED, INC.
21414 68th AVE. SO. KENT WA 98032

TITLE
RAIL GAUGE INSTRUMENT BOX
TAPER

SCALE HALF
DRAWING NUMBER C 65486 REV — SH 1



PARTS LIST			
QTY	ITEM	DESCRIPTION	SPECIFICATION
1	1	BATTERY BOX	65492
1	2	SLIDE "B"	65494
1	3	SLIDE "A"	65493-1
2	4	SLIDE "A"	65493-2
1	5	BATTERY CONNECTOR (MICROPWR)	VJA0186
1	6	BATTERY CLIP MOUNT	65495
1	7	SPRING PIN	65496
2	8	SPRING (EXTENSION)	1/4ø
1	9	LATCH BAR ASSEMBLY	65497
12	10	FHMS #4-40 X 1/4	S STL
2	11	RHMS #10-32 X 3/8	S STL
2	12	RHMS #8-32 X 5/8	S STL
6	13	RHMS #6-32 X 3/8	S STL
6	14	NUT #6-32	S STL
2	15	SHCS #4-40 X 3/8	S STL
2	16	FW #4	S STL
2	17	RHMS #2-56 X 1/4	S STL
1	18	SPRING (EXTENSION)	1/4ø

DASH NO	NEXT ASSY. DWG. NO.	QTY.
1	65486	1

USED ON

REV	DATE	DESCRIPTION	BY	CK
–		FIRST ISSUE		

REVISIONS

TOLERANCES
(EXCEPT AS NOTED)
DECIMAL: X.XX = ±.030"
X.XXX = ±.010"
FRACTION: X/X = ±1/16"
ANGLE: X° = ±2° 125/
ALL MACHINED SURFACES:
ALL DIMENSIONS ARE INCHES.
ALL CIRCULAR FEATURES ON COMMON CENTERLINES ARE CONCENTRIC WITHIN .010" ø.
BREAK ALL SHARP EDGES.

MAKE QTY.	CHARGE NO.		ENGR EXT.
DATE REQ'D.	QUALITY PLAN NO.		EST. HOURS
MACHINIST			ACTUAL HOURS

SHOP INSTRUCTIONS

SIGNED
DATE 10-22-92
DRAWN BY MHM
ENGINEER MHM
CHECKED
APPROVED

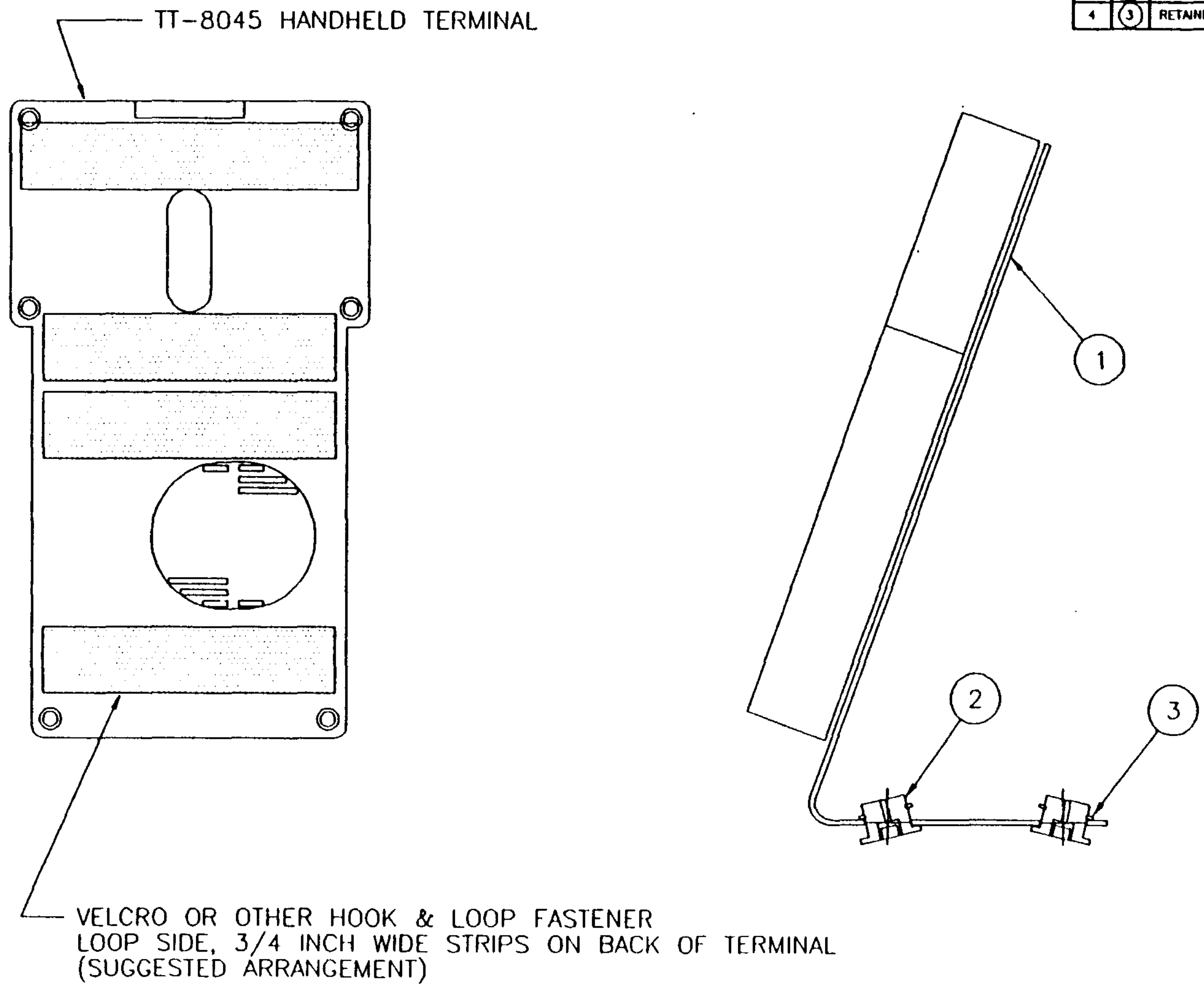
QUEST INTEGRATED, INC.
21414 68th AVE. SO. KENT WA 98032

TITLE BATTERY HOLDER ASSEMBLY
TAPER II

SCALE 1/2 | DRAWING NUMBER A65588 | REV | SH

PARTS LIST

QTY	ITEM	DESCRIPTION	SPECIFICATION
1	1	STAND	DWG NO 67569 SHT 2
4	2	FOOT	DWG NO 67569 SHT 3
4	3	RETAINING RING	TRUARC 5100-50



SHOP INSTRUCTIONS

MAKE QTY.	CHARGE NO	ENGR EXT	
DATE REQ'D	QUALITY PLAN NO	EST. HOURS	
MACHINIST		ACTUAL HOURS	

USED ON

DASH NO	NEXT ASSY. DWG NO	QTY.

REVISIONS

REV	DATE	DESCRIPTION	BY	CK
		FIRST ISSUE		

TOLERANCES

(EXCEPT AS NOTED)
DECIMAL: X.XX = ±.030"
X.XXX = ±.010"
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ANGLE: X° = ±2°
125 ALL MACHINED SURFACES
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ALL CIRCULAR FEATURES ON COMMON CENTERLINES ARE CONCENTRIC WITHIN .010" ⌀
BREAK ALL SHARP EDGES.

SIGNED

DATE 11/15/93
DRAWN BY HOLDEN
ENGINEER HOLDEN
CHECKED
APPROVED

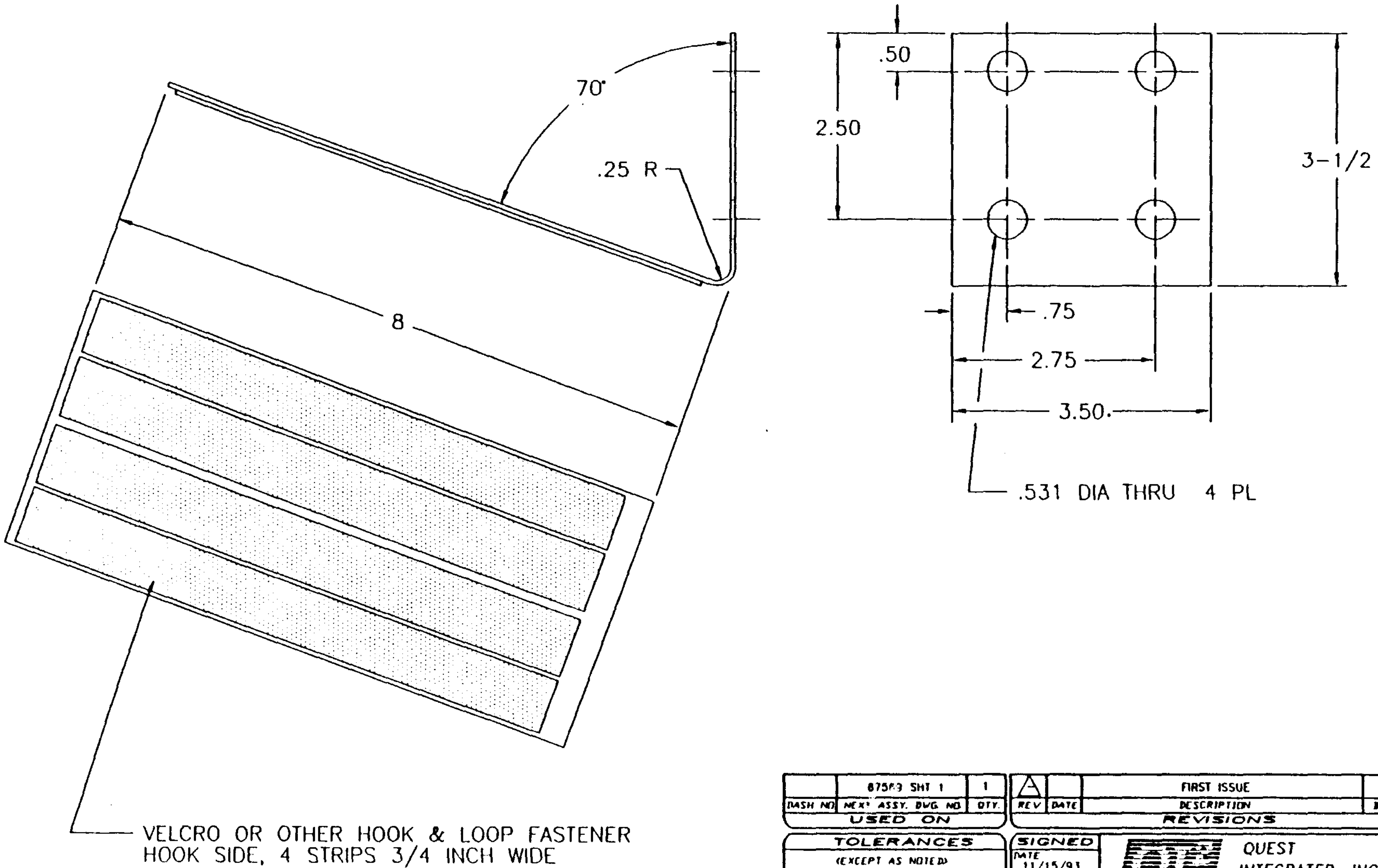
QUEST INTEGRATED, INC.
21414 68th AVE. SO. KENT WA 98032

TITLE PENDANT HOLDER
TAPER II

SCALE 1:2
DRAWING NUMBER A67569 REV — SH1

PARTS LIST

QTY	ITEM	DESCRIPTION	SPECIFICATION
1	1		6061-T6 0.063 THICK



MAKE QTY	CHARGE NO	ENGR EXT.	
DATE REQ'D	QUALITY PLAN NO	EST. HOURS	
MACHINIST		ACTUAL HOURS	

SHOP INSTRUCTIONS

DASH NO	NEXT ASSY. DWG NO	QTY.
	87583 SHT 1	1

USED ON

REV	DATE	DESCRIPTION	BY	CK
△		FIRST ISSUE		

REVISIONS

TOLERANCES
(EXCEPT AS NOTED)
DECIMAL: X.XX = ±.030"
X.XXX = ±.010"
FRACTION X/X = ±1/16"
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ALL DIMENSIONS ARE INCHES.
ALL CIRCULAR FEATURES ON COMMON CENTERLINES ARE CONCENTRIC WITHIN .010"
BREAK ALL SHARP EDGES

SIGNED
DATE 11/15/93
DRAWN BY HOLDEN
ENGINEER HOLDEN
CHECKED
APPROVED

QUEST INTEGRATED, INC.
21414 68th AVE. SO. KENT WA 98032

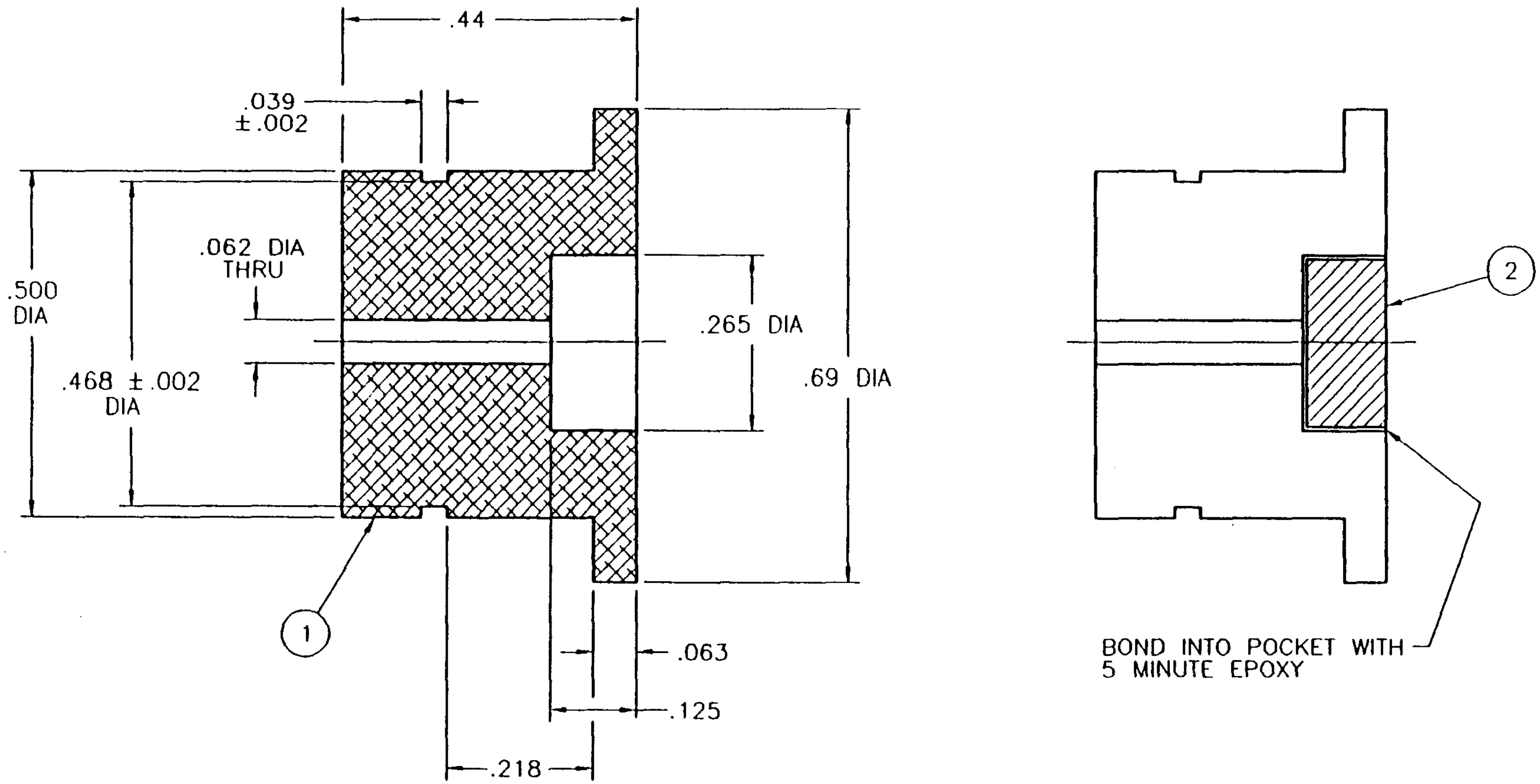
TITLE STAND
TAPER II

SCALE 1:2 DRAWING NUMBER A67569 REV — SH2

THIS DRAWING IS THE PROPERTY OF QUEST INTEGRATED INC. AND NOT TO BE COPIED OR REPRODUCED WITHOUT WRITTEN CONSENT OF QUEST INTEGRATED INC.

PARTS LIST

QTY	ITEM	DESCRIPTION	SPECIFICATION
1	1	FOOT	6061-T6 RD BAR 0.75#
1	2	N-I-B MAGNET	EDMUND SCI N38,429



USED ON

DASH NO	NEXT ASSY. DWG. NO	QTY.
	67569 SHT 1	4

REVISIONS

REV	DATE	DESCRIPTION	BY	CK
-		FIRST ISSUE		

TOLERANCES

(EXCEPT AS NOTED)
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ALL DIMENSIONS ARE INCHES.
ALL CIRCULAR FEATURES ON COMMON CENTERLINES ARE CONCENTRIC WITHIN .010" Ø.
BREAK ALL SHARP EDGES

SIGNED	
DATE	11/15/93
DRAWN BY	HOLDEN
ENGINEER	HOLDEN
CHECKED	
APPROVED	

QUEST INTEGRATED, INC.
21414 68th AVE. SO. KENT WA 98032

TITLE: FOOT
TAPER II

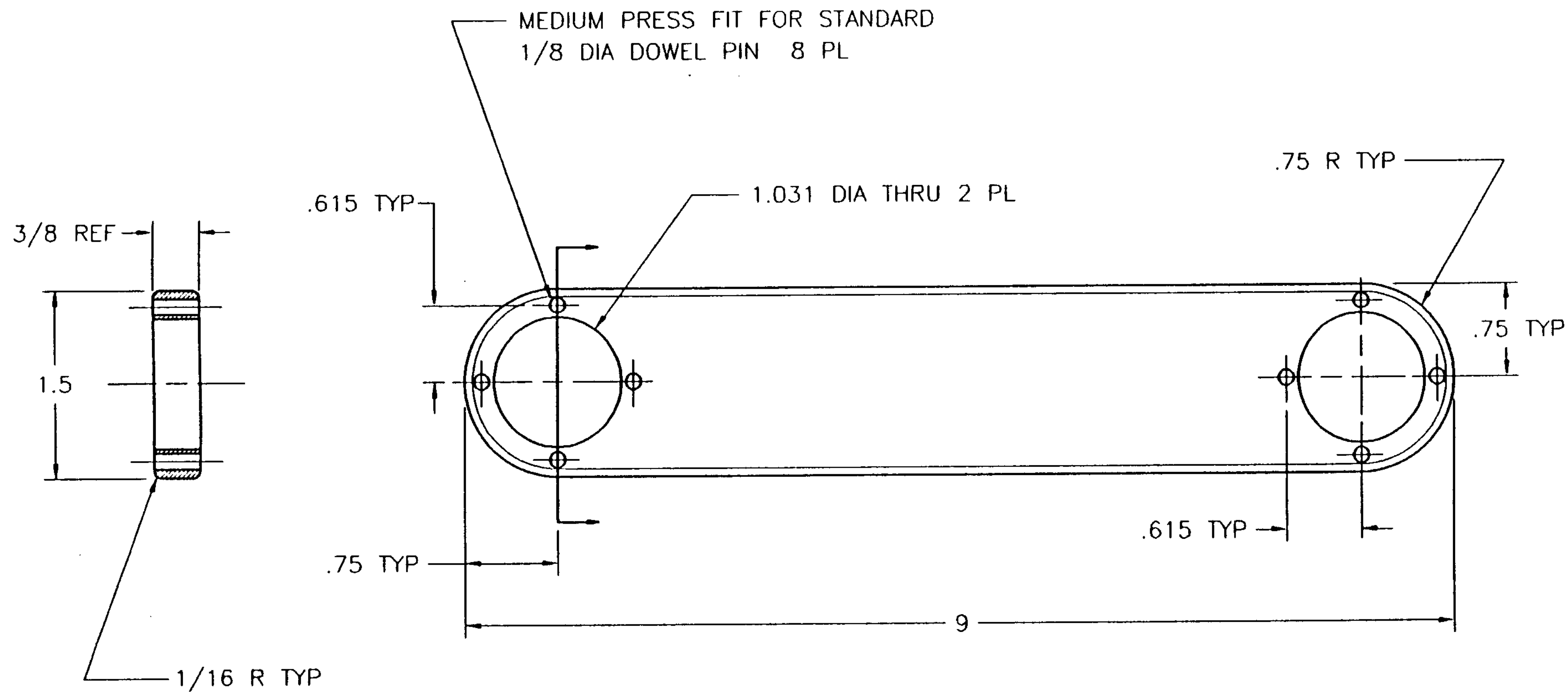
SCALE: 8:1 — DRAWING NUMBER: A67569 — REV — SH3

THIS DRAWING IS THE PROPERTY OF QUEST INTEGRATED INC. AND NOT TO BE ...

MAKE QTY	CHARGE NO	ENGR EXT.
DATE REQ'D	QUALITY PLAN NO	EST. HOURS
MACHINIST		ACTUAL HOURS

SHOP INSTRUCTIONS

PARTS LIST			
QTY	ITEM	DESCRIPTION	SPECIFICATION
1	1	3/8 X 1-1/2 BAR	304 OR 316 SS



MAKE QTY.	CHARGE NO.	ENGR EXT
DATE REQ'D.	QUALITY PLAN NO.	EST. HOURS
MACHINIST		ACTUAL HOURS

SHOP INSTRUCTIONS

DASH NO.	NEXT ASSY. DWG. NO.	QTY.

USED ON

TOLERANCES
(EXCEPT AS NOTED)
DECIMAL: X.XX = ±.030"
X.XXX = ±.010"
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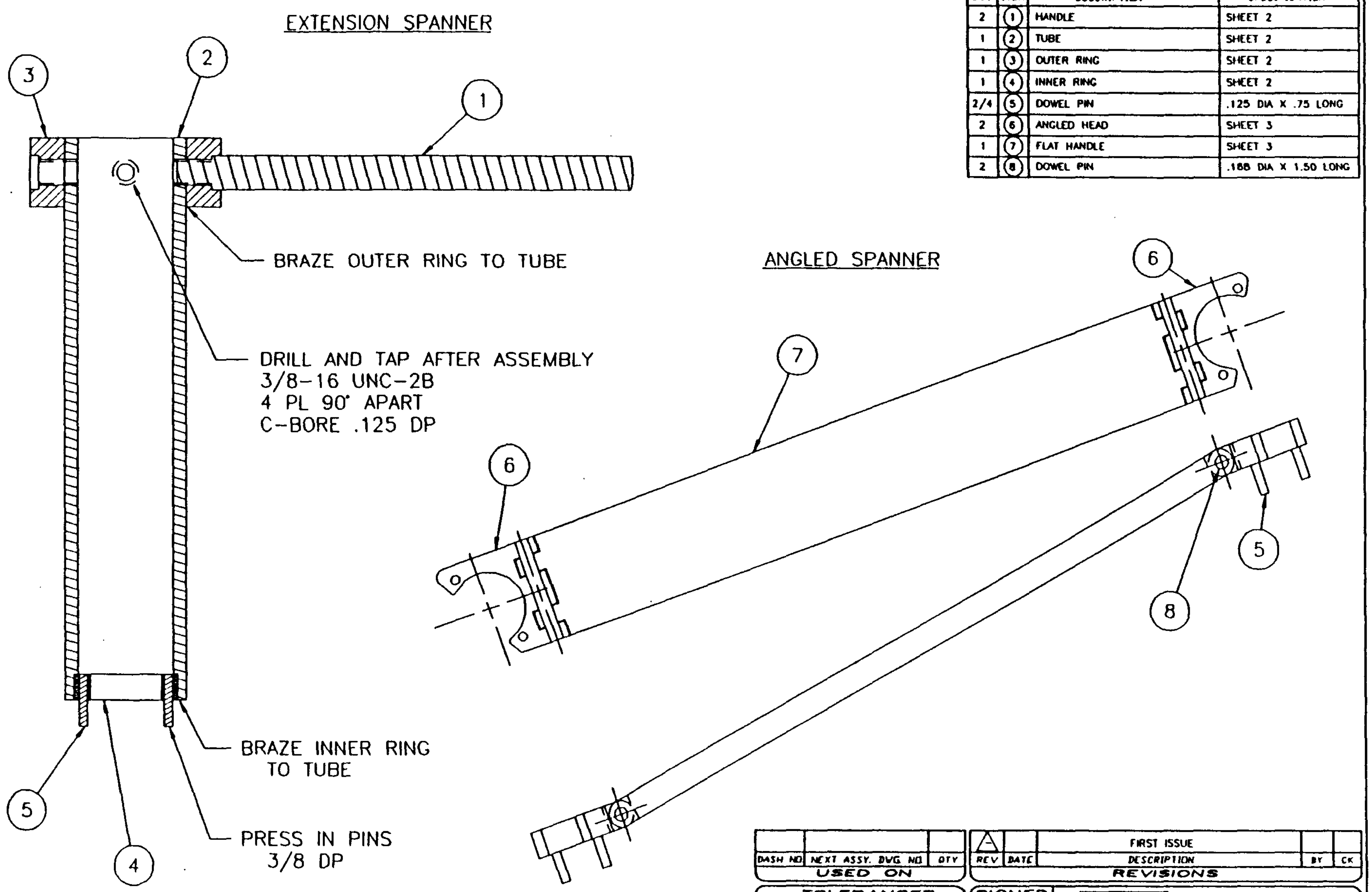
ALL DIMENSIONS ARE INCHES.
ALL CIRCULAR FEATURES ON COMMON CENTERLINES ARE CONCENTRIC WITHIN .010" Ø.
BREAK ALL SHARP EDGES.

REV	DATE	DESCRIPTION	BY	CK
		FIRST ISSUE		

REVISIONS

SIGNED	
DATE 6/16/93	QUEST INTEGRATED, INC. 21414 68th AVE. SO. KENT WA 98032
DRAWN BY HOLDEN	TITLE ADJUSTING WRENCH TAPER II
ENGINEER HOLDEN	
CHECKED	
APPROVED	SCALE 3:4 — DRAWING NUMBER A64259 — REV B — SH1



PARTS LIST

QTY	ITEM	DESCRIPTION	SPECIFICATION
2	1	HANDLE	SHEET 2
1	2	TUBE	SHEET 2
1	3	OUTER RING	SHEET 2
1	4	INNER RING	SHEET 2
2/4	5	DOWEL PIN	.125 DIA X .75 LONG
2	6	ANGLED HEAD	SHEET 3
1	7	FLAT HANDLE	SHEET 3
2	8	DOWEL PIN	.188 DIA X 1.50 LONG

MAKE QTY.	CHARGE NO.	ENGR EXT.
DATE REQ'D	QUALITY PLAN NO.	EST. HOURS
MACHINIST		ACTUAL HOURS

SHOP INSTRUCTIONS

DASH NO	NEXT ASSY. DWG NO	QTY

USED ON

TOLERANCES
(EXCEPT AS NOTED)
DECIMAL: X.XX = ±.030"
X.XXX = ±.010"
FRACTION: X/X = ±1/16"
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BREAK ALL SHARP EDGES.

REV	DATE	DESCRIPTION	BY	CK
△		FIRST ISSUE		

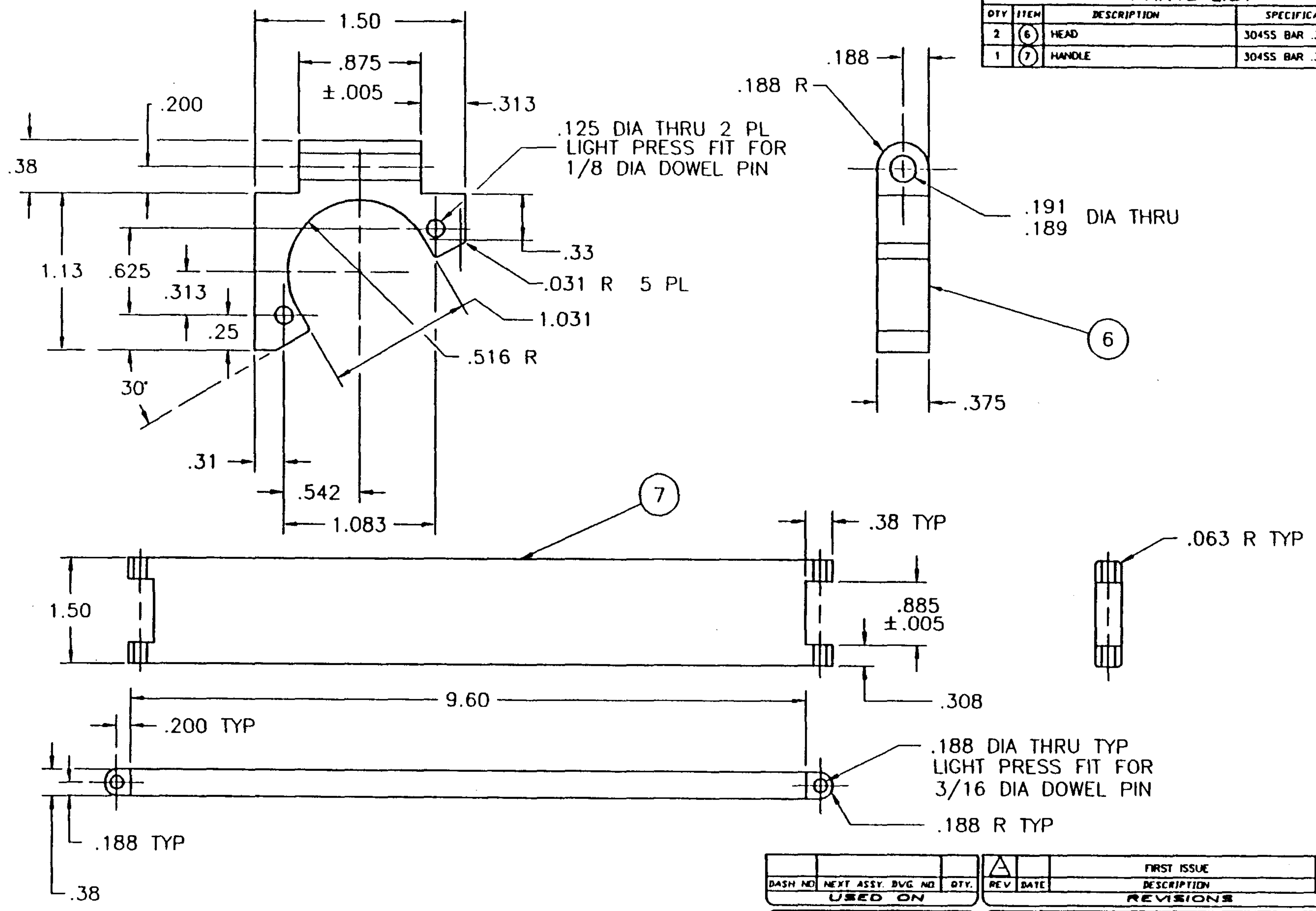
REVISIONS

SIGNED
DATE 11/5/93
DRAWN BY HOLDEN
ENGINEER HOLDEN
CHECKED
APPROVED

QUEST INTEGRATED, INC.
21414 68th AVE. SO. KENT WA 98032

TITLE SPANNER WRENCHES
TAPER II

SCALE 1:2 DRAWING NUMBER A67524 REV — SH1



PARTS LIST

QTY	ITEM	DESCRIPTION	SPECIFICATION
2	6	HEAD	304SS BAR .38 x 1.50
1	7	HANDLE	304SS BAR .38 x 1.50

DASH NO	NEXT ASSY. DWG NO	QTY.

USED ON

REV	DATE	DESCRIPTION	BY	CK
		FIRST ISSUE		

REVISIONS

TOLERANCES
(EXCEPT AS NOTED)
DECIMAL: X.XX = ±.030"
X.XXX = ±.010"
FRACTION: X/X = ±1/16"
ANGLE: X° = ±2°
ALL MACHINED SURFACES: 125
ALL DIMENSIONS ARE INCHES.
ALL CIRCULAR FEATURES ON COMMON CENTERLINES ARE CONCENTRIC WITHIN .010"
BREAK ALL SHARP EDGES

SIGNED
DATE 11/5/93
DRAWN BY HOLDEN
ENGINEER HOLDEN
CHECKED
APPROVED

QUEST INTEGRATED, INC.
21414 68th AVE. SO. KENT WA 98032

TITLE ANGLED WRENCH DETAILS
TAPER II

SCALE 1:2 DRAWING NUMBER A67524 REV — SH3

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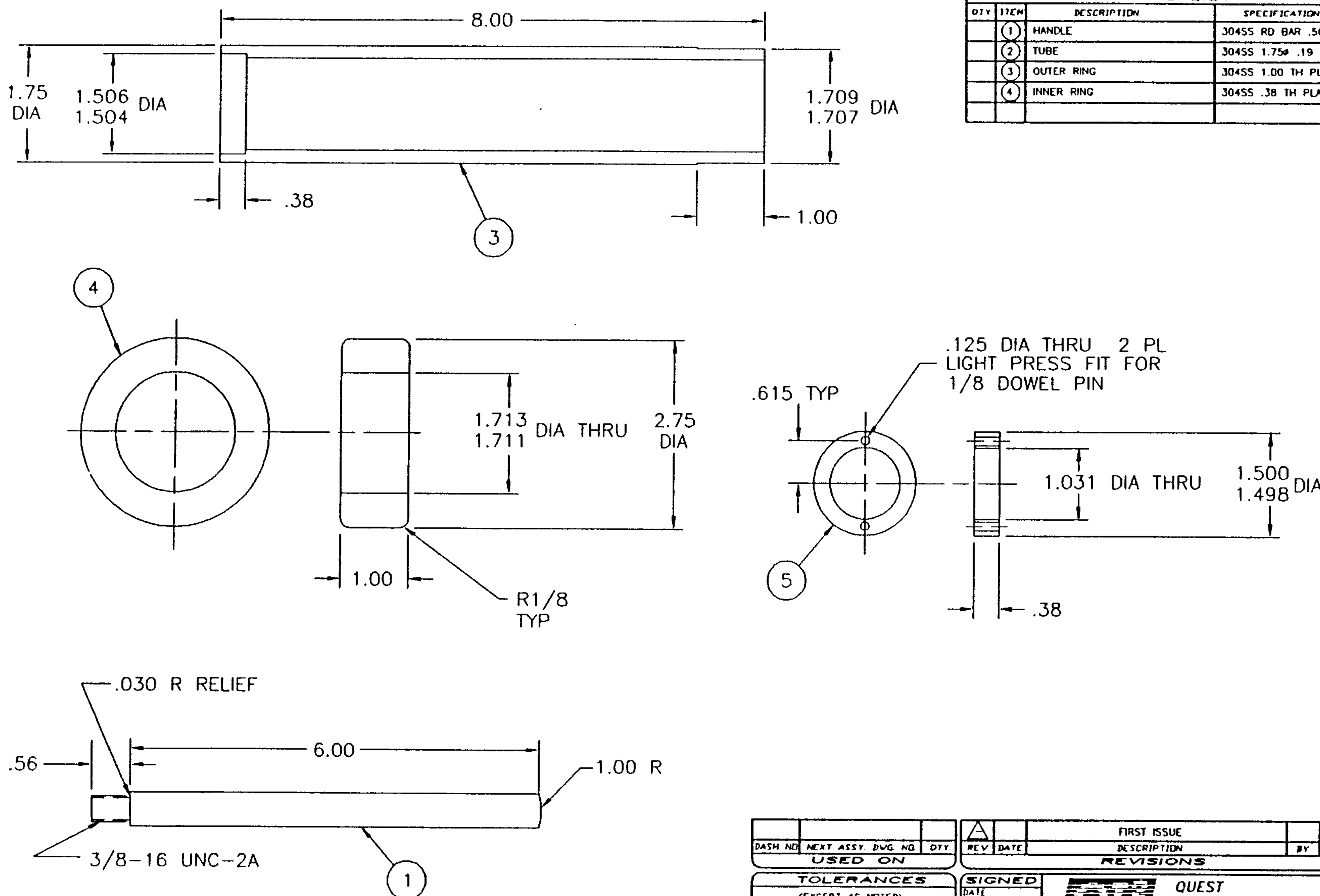
MAKE QTY.	CHARGE NO.	ENGR EST.
DATE REQ'D.	QUALITY PLAN NO.	EST. HOURS
MACHINIST		ACTUAL HOURS

SHOP INSTRUCTIONS

QTY	ITEM	DESCRIPTION	SPECIFICATION
	1	HANDLE	304SS RD BAR .50ø
	2	TUBE	304SS 1.75ø .19 WALL
	3	OUTER RING	304SS 1.00 TH PLATE
	4	INNER RING	304SS .38 TH PLATE

PARTS LIST



MAKE QTY.	CHARGE NO.	ENGR EXT.	
DATE REQ'D.	QUALITY PLAN NO.	EST. HOURS	
MACHINIST		ACTUAL HOURS	

SHOP INSTRUCTIONS

DASH NO.	NEXT ASSY. DWG. NO.	QTY.

USED ON

REV	DATE	DESCRIPTION	BY	CK
△		FIRST ISSUE		

REVISIONS

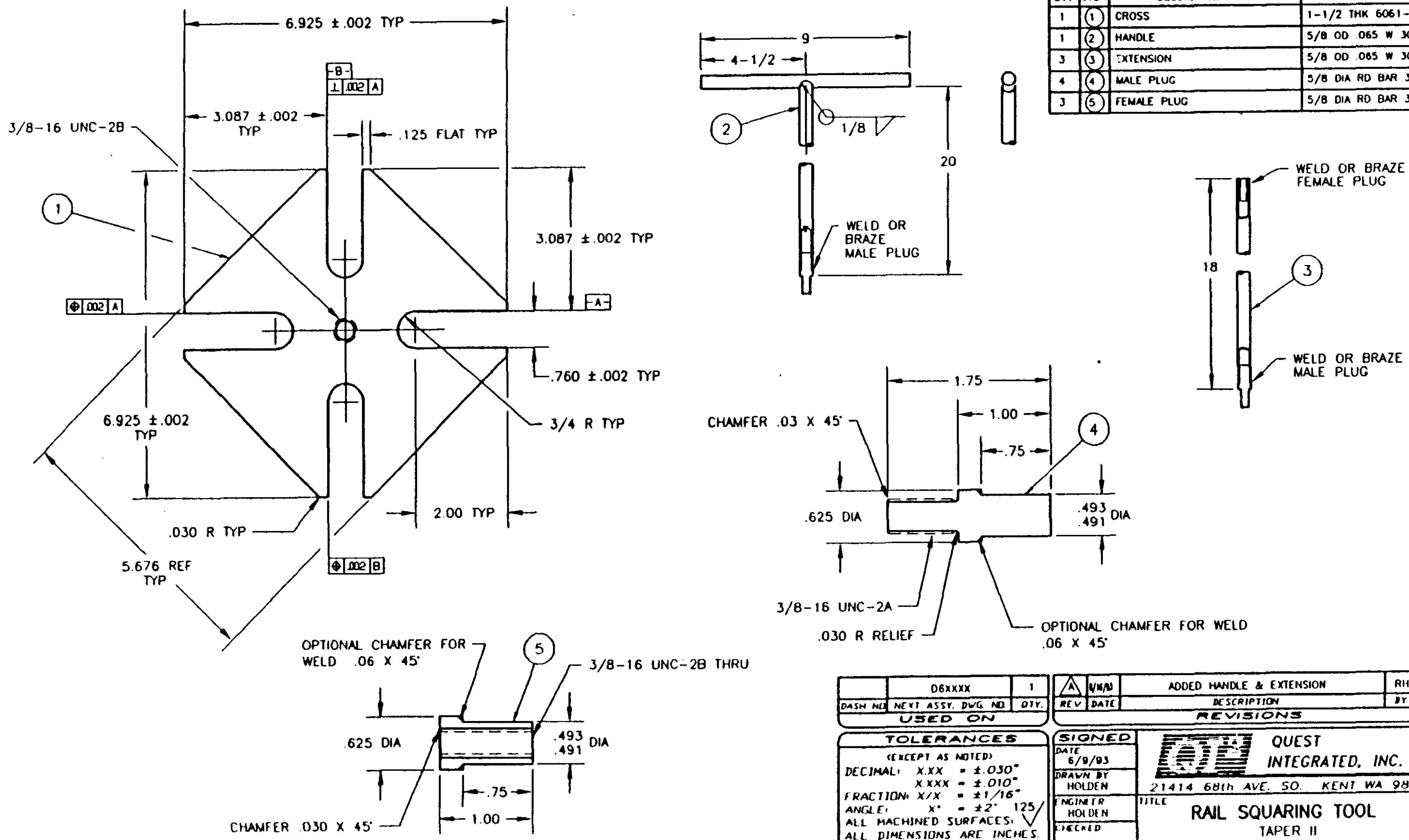
TOLERANCES
(EXCEPT AS NOTED)
DECIMAL: X.XX = ±.030"
X.XXX = ±.010"
FRACTION: X/X = ±1/16"
ANGLE: X° = ±2°
ALL MACHINED SURFACES: 125
ALL DIMENSIONS ARE INCHES
ALL CIRCULAR FEATURES ON COMMON CENTERLINES ARE CONCENTRIC WITHIN .010" ø
BREAK ALL SHARP EDGES.

SIGNED
DATE 11/5/93
DRAWN BY HOLDEN
ENGINEER HOLDEN
CHECKED
APPROVED

QUEST INTEGRATED, INC.
21414 68th AVE. SO. KENT WA 98032

TITLE EXTENSION WRENCH DETAILS
TAPER II

SCALE 1:2 | DRAWING NUMBER A67524 | REV — | SH2



PARTS LIST

QTY	ITEM	DESCRIPTION	SPECIFICATION
1	1	CROSS	1-1/2 THK 6061-T6
1	2	HANDLE	5/8 OD .065 W 304SS
3	3	EXTENSION	5/8 OD .065 W 304SS
4	4	MALE PLUG	5/8 DIA RD BAR 304SS
3	5	FEMALE PLUG	5/8 DIA RD BAR 304SS

USED ON

DASH NO	NEXT ASSY. DWG NO	QTY.
	06XXXX	1

REVISIONS

REV	DATE	DESCRIPTION	BY	CK
A	4/4/...	ADDED HANDLE & EXTENSION	RH	

TOLERANCES

(EXCEPT AS NOTED)
DECIMAL: X.XX = ±.030"
X.XXX = ±.010"
FRACTION: X/X = ±1/16"
ANGLE: X° = ±2°
ALL MACHINED SURFACES: 125√
ALL DIMENSIONS ARE INCHES.
ALL CIRCULAR FEATURES ON COMMON CENTERLINES ARE CONCENTRIC WITHIN .010" ●
BREAK ALL SHARP EDGES.

SIGNED	
DATE	6/9/93
DRAWN BY	HOLDEN
ENGINEER	HOLDEN
CHECKED	
APPROVED	

QUEST INTEGRATED, INC.
21414 68th AVE. SO. KENT WA 98032

TITLE: RAIL SQUARING TOOL
TAPER II

SCALE | DRAWING NUMBER B 66724 REV A SH 1